# Energy Innovation Systems Indicator Report 2012

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# Energy Innovation Systems

Indicator Report 2012

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# Preface

This report is the first report in a series of reports on energy innovation system indicators produced as part of the activities in the “EIS Strategic research alliance for Energy Innovation Systems and their dynamics – Denmark in global competition”.

The work is based on a number of existing statistics and reports. Among these are the pilot report for a Nordic Energy Technology Scoreboard (Klitkou et al., 2010) and parts of the results of the eNERGIA project (Klitkou et al., 2008b). For this report the indicator based tables and figures have been updated and new developments in the discussion of indicators have been included.

Moreover, the report is based on a survey of innovation activities and interaction carried out as part of the EIS project (Borup et al., 2012) as well as on earlier surveys and analyses carried out on Danish and Nordic level (Tanner et al., 2009), (Borup et al., 2008).

The report received also valuable input from a project commissioned by IPTS. This project addressed co-operation patterns and knowledge flows in patent documents in the fields of wind energy, photovoltaic energy and concentrating solar power (Iversen and Patel, 2010). The results relevant for this project have informed this EIS report.

The activities in the EIS research alliance are funded by the Danish Council for Strategic Research, primarily, and by the involved research organisations.

# 1 Introduction

Knowledge about the innovation systems with respect to new energy solutions and technologies is of central importance for understanding the dynamics of change in the energy sector and assessment of opportunities for moving towards more climate-friendly and sustainable energy systems and for socio-economic development in the field, creation of new businesses, work places, etc..

This is the topic that in general is addressed in the research activities of the “EIS – Strategic research alliance for Energy Innovation Systems and their dynamics – Denmark in global competition”. As part of this, the present report gives an overview of the available indicators of energy innovation systems and points out some of the limitations and potentials there currently are in this connection. Focus is on Denmark. Figures for other countries, primarily Nordic or European, are in some cases showed as well, offering a comparative perspective.

## 1.1 Why indicators?

Different dimensions of human activities and conditions have long been subjected to measurement. Measurements, for example, allow comparisons over time and between populations. Compiling measurements can be a useful means in taking stock and in determining the extent of change that may be due to different given factors. In terms of innovation, cross-country comparisons can be used to posit an empirical relation between e.g. knowledge accumulation and growth of output or productivity.

There are some initial caveats which should be noted at the outset of this report. A general one is that sometimes the zeal to measure can obscure or blind one to the purpose of the exercise in the first place. Indicators on the conditions and performance of low carbon energy technology are in many cases still taking shape. International data collection agencies such as the International Energy Agency (IEA), the Organisation of Economic Cooperation and Development (OECD), Eurostat, and others provide information about the established data collection standards and related guidelines which are documented along with limitations. This report presents data collected from such recognised authorities. In applying the data, however, one should remain critical of their use.

A second more specific caveat is that some activities and conditions lend themselves better to measurement than others (Verbeek et al., 2002). Even straightforward measures, such as greenhouse gas emissions, can pose difficulties. The measurement of technology and innovation activities is a far more challenging area that poses a set of general challenges both in terms of defining, collection and interpretation of data (OECD, 1992).

One indicator, or one number, does not in itself offer much insight. Only in comparison or in other ways put in perspective and connected to other bits of knowledge, is true insight obtained. One of the reasons for gathering a number of different indicators together in one report is to establish a basis for insight and an overview that is otherwise rarely made available.

The target groups for the report are primarily policy and strategy makers, researchers, etc., dealing with issues of energy change and innovation on national, societal or sector level, or on the level of an energy technology area as such. Hence, the indicators selected for the report contribute to overview and a general picture of the state of affairs, rather than insight in the details of energy innovation.

It is our ambition that our analyses of indicators of energy innovation systems over the coming years can contribute to opportunities for developing new indicator standards, composite indexes, etc.. As this report is the first in the series, these advanced aspects will not be taken up here. The emphasis will be on establishing the overview and on identifying blind spots, methodological challenges, etc.

Emphasis is on data sources that are as ‘official as possible’, preferably part of general statistics offered by recognized national or international institutions, up-dated annually, etc. This is however a trade-off, as many official statistics do not offer sufficient insight in energy innovation and are too general. Moreover, it is not always that the general, international databases have the best and most complete data. Therefore, a number of indicators are included even though they are not officially established and not up-dated regularly.

## 1.2 Structure of report and indicator presentation

Chapter 2 firstly introduces the analysis perspective of innovation systems and suggests a row of indicators that are relevant for measuring energy innovation systems. After that, challenges when addressing renewable energy technologies and other low carbon technologies for sustainability are described. Finally, the chapter discusses the landscape of existing statistics and its current challenges and limitations.

Chapter 3 presents figures on a number of selected indicators. This includes methodological remarks and comments on individual indicators. The indicators are organised in three main categories:

| | |
|---|---|
| 1. Input indicators | The platform for the energy innovation system and political support and investments in it. |
| 2. Throughput indicators | The working and dynamics of the energy innovation system – the activities and processes. |
| 3. Output indicators | The performance of the energy innovation system – the resulting outcomes. |

The chapter is structured accordingly with subsequent sections on input, throughput and output indicators. General background and structural indicators are in some cases also relevant to mention. This is done in connection to the input indicators, or where otherwise mostly appropriate.

Energy innovation systems are not machines. The categorisation in input, throughput, and output indicators shall not be taken as an suggestion of a mechanical understanding of energy innovation systems where a wanted output can be obtained 'just' by adjusting on the input side. Rather energy innovation and change are highly complex processes appearing through often long-lasting and multifaceted efforts. Linear development chains are not adequate models of innovation and change in the energy systems. Spiral-like models with many circular processes and feedbacks offer a better explanation of reality as change often to some extent grows out of the existing.

The geographical coverage of the report is defined to Denmark and a set of benchmark countries where comparable data is often available. We moreover explore the potential time-series for different data. Ideally, indicator data for every year, ten, twenty, or more years back in time would be nice and preferred for the set of indicators in general. In many cases, this is however not realistic and shorter time periods as well as indicators that are more infrequently updated are included as well.

The technological focus is on low-carbon technologies for sustainable energy systems, primarily renewable energy technologies like wind energy, bioenergy and solar energy, and energy efficiency technology. In some cases also other technologies are covered, e.g., conversion technologies like fuel cells and other areas of renewable technology like geothermal energy and wave energy that are until now of smaller importance for Denmark.

# 2 Background – concepts and issues

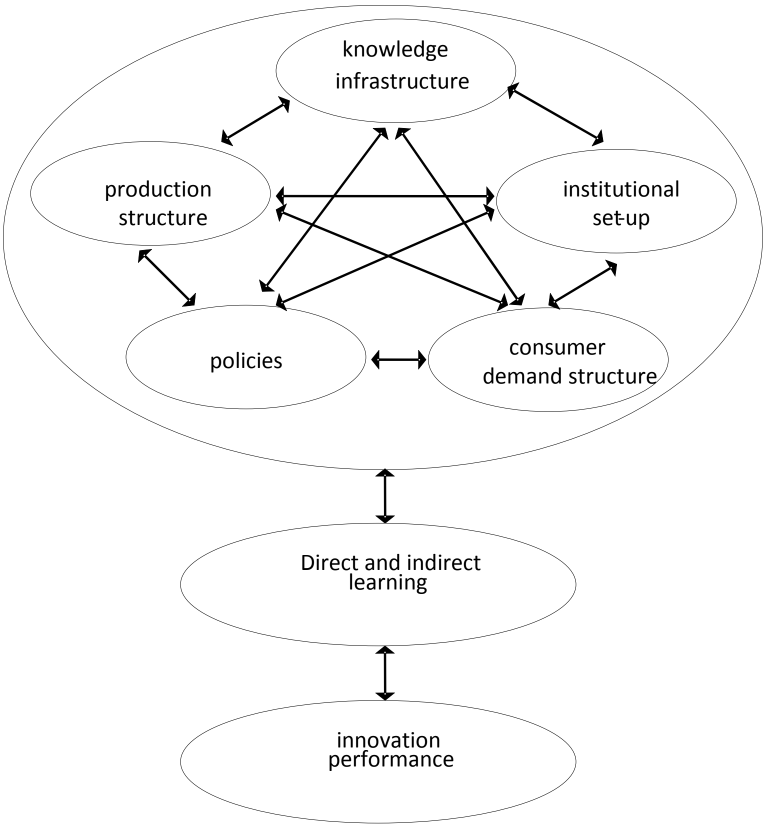
## 2.1 Innovation systems

Analyses of innovation systems have over that latest 20 years documented that patterns and conditions of innovation are not identical across the world but vary from country to country as well as between sectors and technology areas (Edquist, 1997; Edquist and Hommen, 2008; Hekkert et al., 2007; Lundvall, 1992; Malerba, 2002; Nelson, 1993).

Differences between the innovative performance of different innovation systems can be ascribed to differences in the specific constitution of the learning and knowledge production, in the industry and market structures, and in the institutional set-up. This is illustrated in the figure below. The capability of change and innovation can usually not be explained by one factor alone, e.g. by science and research alone, by market forces alone, or by policies and institutions alone. On the contrary, the system character of innovation systems refers to the fact that development and innovation appear in complex interplay between numerous actors, e.g., companies, their customers and sub-suppliers, research and educational institutions, authorities, interest organisations, etc., and through a multitude of activities and interaction processes.

This makes it a challenge to establish a useful set of indicators of energy innovation systems. It points to that the quality of an innovation system cannot be measured by one, single measuring dimension only. Instead a combination of indicators must be employed.

*Figure 1: Innovation systems and their innovation performance.*




Source: Gregersen and Johnson (1997)

Central constituents of innovation systems are the set of actors involved, their networks, the institutions, and the infrastructure developed including e.g. communication and knowledge systems, energy and transportation systems, market structures, standards and certification systems. In its' most general sense, an innovation system can be defined as "the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge" (Lundvall, 1992, p. 12). Knowledge is hence central, but only in the broad sense that includes both informal knowledge and formalised knowledge. By employing the term learning, innovation system analyses ensure this and address knowledge and competence build-up broadly, ranging from market-based learning, learning-by-using and learning-by-doing over entrepreneurial experimentation and industrial product development, to formalised knowledge production, research and educations at universities.

In line with Lundvall's definition of innovation system, "innovation" can be seen as an original contribution to the stock of knowledge in the economy (Verspagen, 1994). Innovation process hence encompasses a series of scientific, technological, organisational, financial and commercial activities, whose boundaries are not necessary sharp. The underlying activities and the overall process are furthermore not homogeneous, but may be particular to a given situation; they are not set in stone but may change, etc.

**Maturity and functions in establishment of new technology areas**

The dynamics of innovation systems differ between mature areas where industrial networks and market applications are well developed, and immature areas where the networks are scattered and market application has not, or only to a small extent, been reached (Foxon et al., 2005; Jacobsson and Bergek, 2004). In mature areas, industrial companies, consumers, markets, and industrial interest organisations are usually central and the number of actors is high. In immature areas other types of actors, e.g., policy makers, public agencies, research communities, environmental interest organisations, or public movements can often be more central and the number of actors will typically be smaller. The differences between mature and immature areas are a challenge for establishment of a set of indicators of energy innovation systems, not only in sense of measuring whether it is mature or not, but also in the sense of being able to detect dynamics and characteristics in both kinds of areas. Change from an immature to a mature situation is moreover a complex and usually long-lasting process. This is a further measuring challenge.

*Table 1: Functions of innovation systems for establishing new technologies for sustainability (Hekkert and Negro, 2009) and examples of indicators.*

| Functions: | Examples of indicators: |
|---|---|
| Entrepreneurial activities and experimentation | - Experimental application projects<br>- New product introductions<br>- New businesses |
| Knowledge development (learning) | - Scientific publications<br>- Technology application (learning-by-using)<br>- R&D funding<br>- Patents |
| Knowledge exchange in networks | - Collaboration patterns<br>- Demonstration projects<br>- Network participation<br>- Conferences and debate meetings<br>- Interest organisations (industrial and environmental) |
| Market formation | - Market application<br>- Public market support<br>- Trade and exports<br>- Standards and certifications |
| Mobilization of resources | - R&D funding<br>- Investments<br>- Personnel<br>- R&D and others |
| Guidance of the search – shared visions | - Policy action plans<br>- Shared strategies and roadmaps<br>- Debate activities |
| Legitimacy | - Public opinions on energy technologies and systems<br>- Regulatory acceptance and integration |

The difference between mature and immature areas is addressed in a number of analyses of technology-specific innovation systems (Hekkert and Negro, 2009; Jacobsson and Bergek, 2004). It is identified that in order for new technologies to move towards a more well-established and mature situation, a number of activities, or 'functions' in the innovation system are typically important. The functions are shown in Table 1 together with examples of indicators that are relevant in connection to the individual functions.

The functions are overlapping and should not be understood as mechanical or functionalistic building blocks. Moreover, the functions are activities considered on a relatively general level. The specific interaction patterns and development dynamics within and between the different functions can take on many shapes. The point is, however, that the functions generally appear in connection with development of a new technology area, at least if the technology becomes successful and obtains widespread application; and maybe, ultimately, changes the existing technology regimes in the sector. This point is highly relevant when considering energy innovation and changes towards more sustainable energy system.

The conceptual framework established by the OECD in the early 1990s for collecting and interpreting data on technological innovation and R&D provides a useful point of reference for this exercise. However, the first edition of the 'Oslo Manual' on the measurement of scientific and technological activities defined innovation rather narrowly in terms of new products and processes and significant technological changes in product and processes (OECD, 1992). However, this was not sufficient for understanding innovation systems. The OECD's 'Frascati Manual' for analysing R&D noted that innovation activities can only really be measured indirectly, using input and output indicators (OECD, 1994). The Frascati manual listed the following six activities for innovative activities (OECD, 1994, p. 20).

- Tooling-up and industrial engineering
- Manufacturing start-up and pre-production development
- Marketing for new products
- Acquisition of disembodied technology
- Acquisition of embodied technology
- Design.

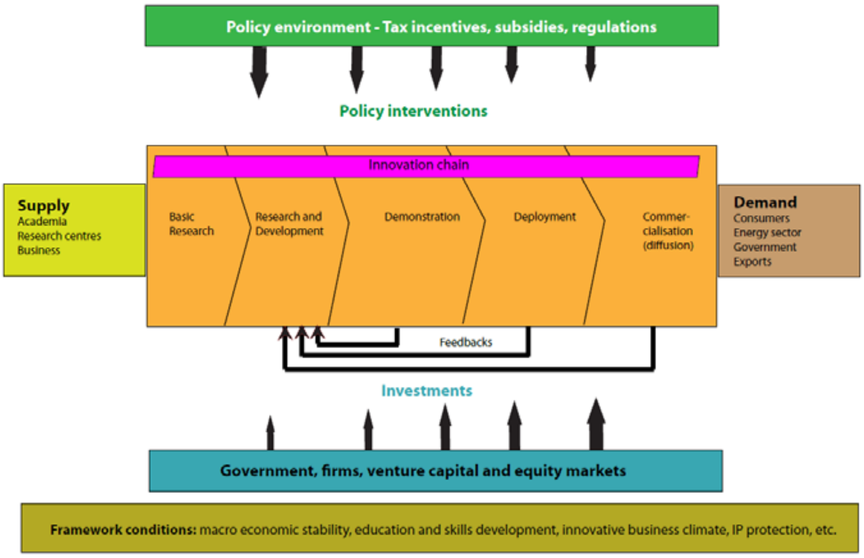
They can be understood as important build-up activities in the perspective of an individual company, but they are also not sufficient for understanding innovation systems.

Since the beginning of the 1990s the Oslo Manual has been developed further. In 2005, with the third edition the innovation measurement framework was expanded in three ways: (1) the role of linkages between firms and institutions was emphasised; (2) innovation in less R&D intensive industries was more recognised; and (3) in the definition of innovation was included also organisational innovation and market innovation (OECD, 2005, p. 6f.). These changes have contributed to a shift from a R&D dominated view on innovation. Organisational innovation is important for understanding learning capabilities in firms and marketing innovations are important to understand interaction with customers and demand-driven innovation processes.

The *analysis of linkages* is necessary to capture the diffusion of knowledge in technological innovation systems. For analysing linkages the Oslo Manual (2005) proposes following types of linkages: (1) *open information sources* which do not require the purchase of IPR, such as R&D journals, patents, standards, professional conferences, public regulations etc., (2) *acquisition of knowledge and technology* either embodied in capital goods (machinery, equipment or software) or acquisition of external knowledge (licenses, designs, trademarks etc.) or services provided by commercial or public sources including designing activities, testing and engineering services, (3) *innovation cooperation* with other firms or public research organisations.

The following figure lays out the schematic dimensions of a generic innovation process in the context of a set of external factors that will affect innovative activities (IEA, 2008). These external or structural elements include policy factors as well as underlying conditions such as access to a skilled labour force. It can be used for distinguishing between different types of support measures, the importance of the policy environment and other framework conditions and feedback loops from demand back to the supply side.

*Figure 2: Innovation Systems and measurements: application to the field of renewable energy.*




Source: adapted and modified from Grubb, 2004 and Foxon, 2003 and ETP 2008

We distinguish between input, output and throughput indicators following Grupp and Schwitalla's taxonomy (Grupp and Schwitalla, 1989). *Input indicators* or *resource indicators* include a diverse set of measures for the allocation of human and other resources to the innovation process. Common input measures include R&D outlays and R&D personnel. They are among the most standardised and used measures of innovative activity. These measures however generally do not pick up input to other innovation activities that are not directly associated to R&D. Moreover, collaborative R&D efforts or R&D activities of international industry players across national borders are difficult to capture by national data.

*Output indicators* according to Grupp and Schwitalla attempt to capture the economic effects of the innovative activity in question. However, measuring output is more challenging. One challenge is that economic effects are not the only interesting products of innovation processes. There are others such as a learning effect which will only indirectly contribute to the economic bottom-line; or changes in energy systems and in the opportunities for energy production or energy consumption that can imply changes also concerning climate impacts. The second is that it is not always easy to distinguish the economic effects of the innovative activity from that of other activities taking place in parallel. Changes at the energy system level, such as the energy mix of a country, the access to renewable energy resources or the declining access to fossil energy sources, can have a considerable impact on the future possibilities and direction of the development of the innovation system.

In addition to the standard measures of input and output indicators, a third class of measure is so-called *by-put* or *throughput* indicators (Grupp and Schwitalla, 1989). Throughput indicators are measures that attempt to capture the intermediate products of the innovation process, e.g. those often emanating from formal R&D processes, but also many other processes which are not related to R&D can be measured as throughput indicators. Throughput indicators are for example patents, bibliometric, and citation statistics. Table 2 provides a presentation of these categories of measurement in terms of their function during the innovation process.

*Table 2: Functions of technological innovation systems and possible linkages to input, throughput and output indicators*

| *Functions* | *Input indicators* | *Throughput indicators* | *Output indicators* |
|---|---|---|---|
| Entrepreneurial activities and experimentation | | Experimental application projects | New product introductions<br>New businesses |
| Knowledge development (learning) | R&D projects | Scientific publications<br>Patents<br>Citations<br>User-driven innovation processes<br>Demonstration and trial projects | Technology application (learning-by-using) |
| Knowledge exchange in networks | R&D networks | Demonstration projects<br>Collaboration patterns<br>Cluster participation<br>Interest organisations<br>Conferences | |
| Market formation | Public market support | Standards and certifications | Market application<br>Market shares<br>Trade and exports<br>Environmental impacts |
| Mobilization of resources | Public R&D funding<br>Business R&D<br>Investments<br>R&D personnel<br>R&D programmes | | Employment |
| Guidance of the search – shared visions | Policy action plans<br>Shared strategies and roadmaps | Debate meetings<br>Strategy networks<br>Scenarios and foresight projects | Industrial strategies |
| Legitimacy | Regulatory acceptance and integration | Public opinions on energy technologies and systems | |

## 2.2 Low carbon technologies

The nature of low carbon energy technologies pose a number of particular measurement challenges in addition to the general issues mentioned above.[1] One challenge is how to measure emerging technologies (IEA, 2006). A number of low carbon energy technologies are interesting to track. They are still not mature. An additional challenge is that the set of technologies in question vary not only in their technical maturity but also in the maturity of their intermediate and end markets, the industrial networks, etc. This raises the question of how to account for the differences between and within the different types of renewable energy technologies.

This has clear implications for the degree to which input, through-put and output measures are applicable for the individual technologies. We can distinguish between three groups of technologies, but there are overlaps and competition between these groups of technologies (IEA, 2006):

(i) technologies which have already reached a considerable degree of maturity, such as hydropower, biomass combustion, onshore wind and geothermal energy;

[1] See Smith (2008) for a discussion.

(ii) technologies which are undergoing rapid development such as solar energy, offshore wind power and modern forms of bio-energy;

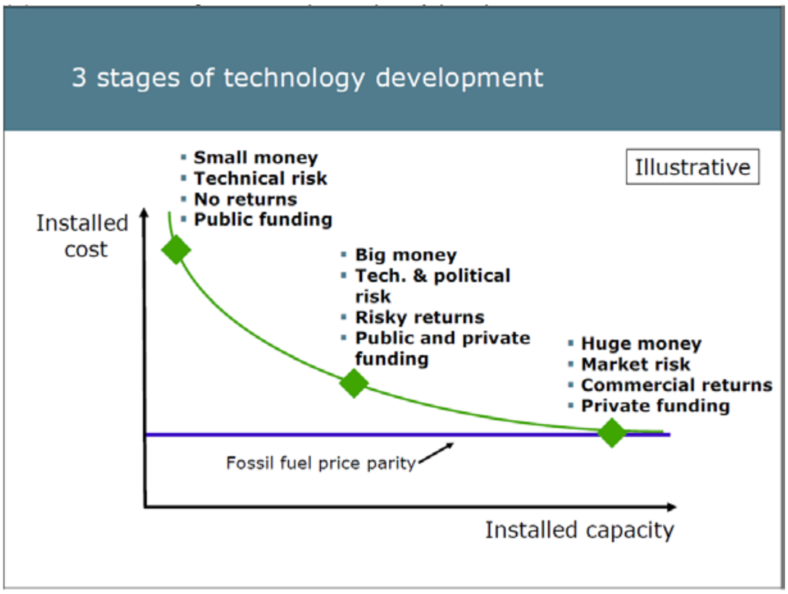
(iii) technologies which are presently in developmental stages such as concentrating solar power, ocean energy, improved geothermal, $CO_2$ capture and storage and integrated bio-energy systems.

A further set of challenges is associated with the scale of the technologies. A major aspect here is that the technological innovation systems for ”low carbon” technologies can involve the deployment of large-scale experimental sites to demonstrate and test different modes of the technology (e.g. carbon capture and storage or offshore wind). These deployment/demonstration sites can require large allocations of public and private resources without providing immediately profitable output. Standardised statistics need to be developed to capture this peculiarity.

Another aspect to consider is associated with scale and the involvement of the public sector. Energy systems tend to be public or semi-public owned, at least in Northern Europe. These technologies are not necessarily stand-alone technologies but may involve significant changes in different parts of existing value chains. For example biofuels require change or complementary developments in engine manufacturing as well as fuel distribution. A first implication that is caused by the systemic of the technologies is that cooperation is likely to be important during the development and deployment of the technologies. Public-private cooperation is one way to overcome resistance and path dependency in the energy sector. Strategic oriented energy companies are often investing heavily in R&D and in many cases do so in close collaboration with research organisations. Measures of cooperation are therefore important, but difficult to get. The innovativeness of the public sector and public procurement of new energy technologies facilitate the successful development of low-carbon energy technological innovation systems and they should be measured to improve our understanding.

A second implication is that the deployment of the technologies may face different degrees of resistance from established and competing systems based on other (e.g. carbon-based) energy sources. A degree of coordination and guidance of the search is necessary in order to overcome such resistance. This implies coordination-costs to facilitate deployment of the emerging technological systems. Figure 3 from Grubb (2004) illustrates that these technologies face a fundamental challenge in competition with the established and pervasive fossil fuel paradigm. It suggests first that an overall measure for the dissemination of renewable technologies will ultimately be their ability to compete with the costs of energy generation based on fossil fuels. Switching costs are very high and build barriers for further development and deployment of emerging low carbon energy technologies.

*Figure 3: Main stages of technology development.*



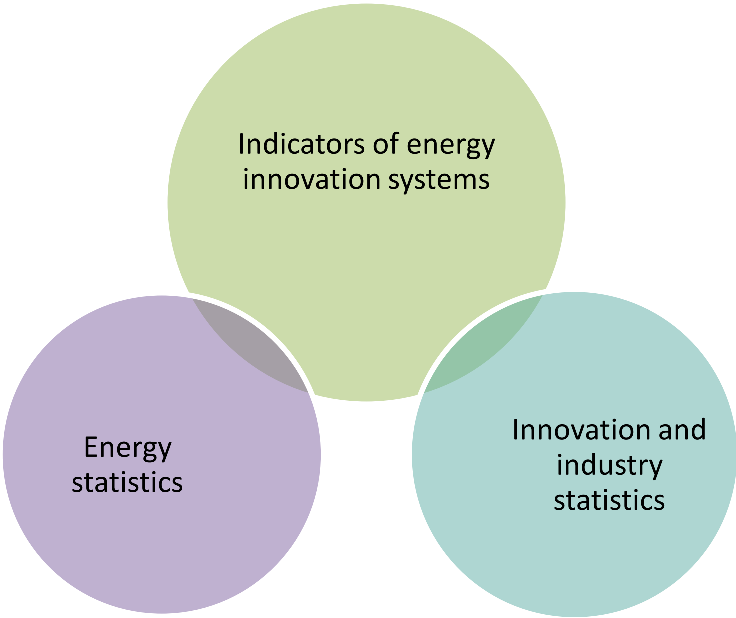

Source: Grubb (2004)

Another feature is that technologies related to fossil fuels do not stand still. Innovation also continues to improve the efficiency of fossil fuels. Following Grubb, this suggests the use of data on R&D budget for fossil fuels as a measure of *carbon-lock-in*, i.e. comparison of expenditures on the different groups of technologies in IEA's RD&D budget indicator – energy efficiency, fossil fuels, renewables and nuclear technologies, hydrogen and fuel cells, other power and storage technologies, total other technologies or research (Grubb, 2004). See also Kaloudis & Pedersen (Kaloudis and Pedersen, 2008) on the use of R&D for a composite of all energy production technologies. In this context it is useful to appreciate that different low-carbon energy technologies may represent incremental, disruptive, or radical modes of innovation (Smith, 2008). Different technologies have different development rates, which in turn implies different degrees of public funding to overcome coordination costs, technological and market uncertainty, and rigidities in existing structures.

## 2.3 Between energy systems and innovation – existing statistics

In the pursuit of a useful set of indicators of energy innovation systems, two existing fields of statistics constitute main pillars of references where much can be drawn from: 1) Energy statistics; and 2) Industry and innovation statistics. Energy statistics is well-established in many countries. It monitors the energy systems and their development over the years. Apart from general figures on energy consumption and energy production, the national energy statistics in some countries also include data on amongst other things energy sources, climate emissions, and energy production by different energy technologies; renewables as well as others. On international level, the national statistics are gathered by a.o. Eurostat and the International Energy Agency (IEA). Well-established R&D statistics are also available for Denmark as well as internationally where the International Energy Agency collects data from a large number of countries on public R&D support within different areas of energy technology.

*Figure 4: Energy statistics and innovation and industry statistics as important sources and reference points for establishment of a set of energy innovation system indicators.*




Industrial innovation statistics have been developed in the latest decade both on national, international and European level. Though the schemes of innovation statistics have become more well-established, they still often change in contents from one time they are run to another. A degree of harmonized approach among the European countries is obtained, enabling comparison between countries and common publishing in the Communities Innovation Surveys (Eurostat) and the European Innovation Scoreboards and, in the most recent years, the Innovation Union Scoreboards (EC DG Enterprise and Industry). The innovation statistics can provide information on e.g. enterprises' R&D investments, frequencies of new product introductions, etc.

In the background behind the innovation statistics are the long well-established statistics fields of trade and industry statistics. Through the trade and industry statistics, the domestic and international trade of products can be illuminated.

What limits the use of the statistics on innovation, trade and industry for our purpose is that they usually do not address the energy sector specifically and that they only to a limited extent cover energy technology products as individual product categories. For example, many renewable energy technologies do not have their own product categories in these statistics. Moreover, the indicators included in the schemes of industry and innovation statistics are seldom about innovation systems as such, but primarily about innovation in the sense of product introductions and business development. The data is gathered on the level of individual companies, i.e. the innovation statistics do usually not provide insight in innovation considered on a system level or on societal level.

Some of the other major gaps in the existing statistics and indicator schemes are amongst other things a lack of indicators of other types of knowledge production than formalised, scientific knowledge (e.g. industrial competence build-up and know-how, learning-by-doing and learning in interaction between other types of actors than research institutions). Concerning application-based learning (learning-by-using), though, there is one important indicator established, namely the indicators of application of different energy production technologies in the domestic energy systems. The more detailed characteristics of user- and demand-driven innovation are however less well reflected in the existing statistics. Another major gap in the existing statistics is developments in actor landscapes, including industrial supply chains, broader innovation networks and actor alliances in different areas of energy technology.

# 3 Indicators and methodological considerations

## 3.1 Input measures

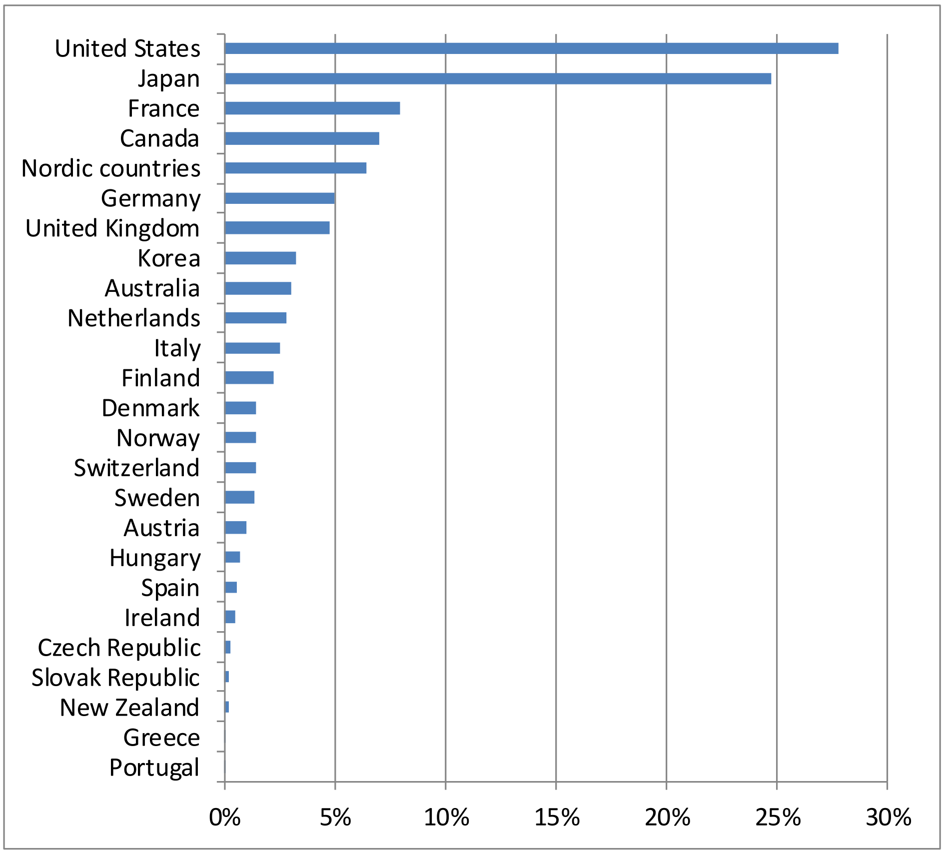
### 3.1.1 Public RD&D investments

The report will feature a set of technology specific input measures are: expenditure on research, development and demonstration activities (RD&D expenditure) decomposed to identify the demonstration dimension.

The IEA RD&D statistics are used as input measures. The IEA energy R&D statistics are collected from government R&D funders and use a scientific/technical nomenclature and are publicly accessible. The budgets are reported on a level of detail that makes it possible to distinguish between the energy technologies used in this report. The IEA database also covers 17 EU Member States. All Nordic countries, with the exception of Iceland are included in the database. The database allows for an analysis of public energy RD&D investments over a long time period. In this report values from mid-1970 to the latest available data, 2010 has been covered. The tables give data for every second year.

On top of research and development budgets the IEA database covers *demonstration budgets*. Demonstration projects are large “test” projects which are not yet operating on a commercial scale. Demonstration budgets are however scarcely reported in the database. As has been explained elsewhere most IEA member countries do not provide data on funds towards demonstration, or do not report them separately (Wiesenthal et al., 2009). Demonstration budgets are typically available since 2004 and for the Nordic countries some data is available, but the systematic reporting and collecting of demonstration budgets need to be improved further.

*Figure 5: Public energy RD&D budgets as percentage share of estimated total IEA budget in 2010. Source: IEA*




Note: Four IEA member countries have not reported: Belgium, Luxembourg, Poland, and Turkey.

An indicator for the need of international RD&D energy cooperation has been constructed by calculating the countries' share of public energy RD&D budgets of the overall IEA spending. The Nordic countries budgets for energy RD&D combined constitute about 6.4% of the total IEA budget in 2010, while Japan and USA give combined more than 52.5% of the total IEA funding (see Figure 5). A conclusion from this is that international research cooperation is essential, especially for small countries in order to increase their access to a larger pool of resources and strategic knowledge, generate synergies and avoid duplication.

In the next figures the trends in RD&D budget distribution over the main groups are illustrated, as classified by the IEA:

*Table 3: Classification of main energy RD&D groups in IEA RD&D statistics.*

| | |
|---|---|
| I. | Energy Efficiency |
| II. | Fossil fuels |
| III. | Renewable energy sources |
| IV. | Nuclear fission and fusion |
| V. | Hydrogen and fuel cells |
| VI. | Other power and storage technologies |
| VII. | Other cross-cutting technologies or research |

For Denmark Figure 6 shows dominant position of public funding of RD&D on renewable energy sources, hydrogen and fuel cells and other cross-cutting technologies, while funding of RD&D on fossil fuels and nuclear fission and fusion is marginal. For Norway the picture is different (see Figure 7). Here has dominated RD&D on fossil fuels and to a lesser extent renewable energy. For Sweden and Finland the focus was on energy efficiency and renewable energy sources (Figure 8 and Figure 9).

*Figure 6: Denmark, Mill. €. RD&D budgets for main groups, 1975-2010. Source: IEA*

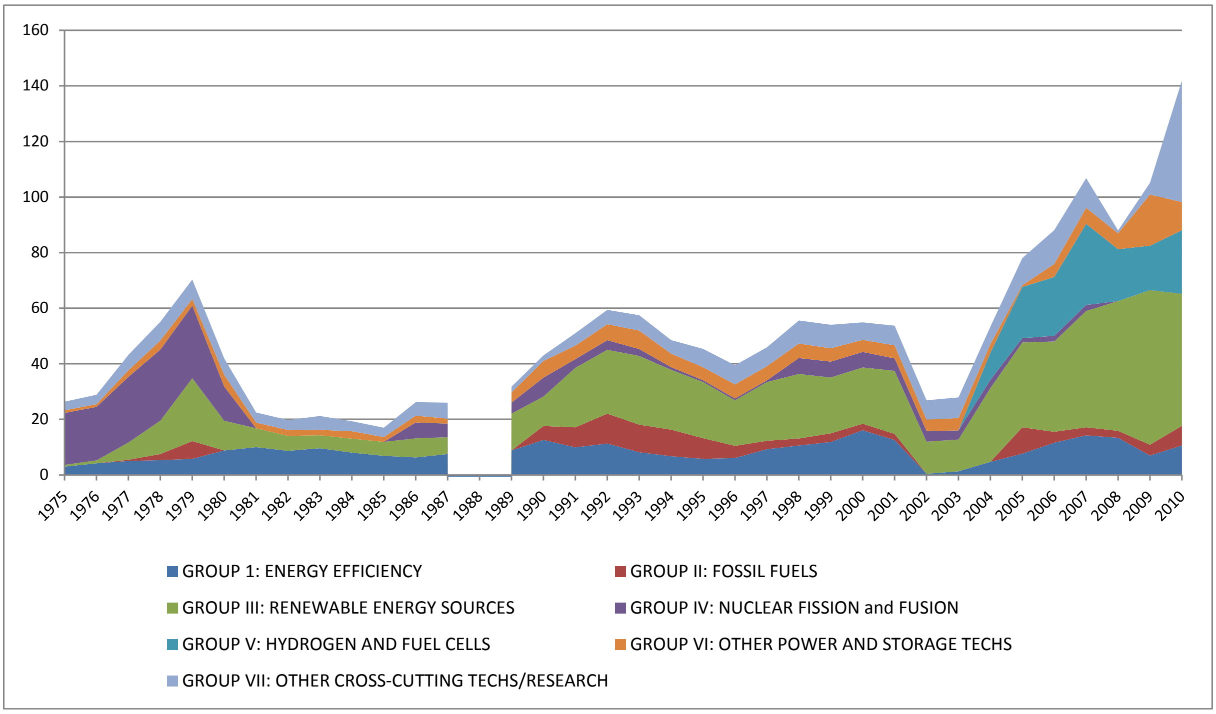


*Figure 7: Norway, Mill. €. RD&D budgets for main groups, 1975-2010. Source: IEA*

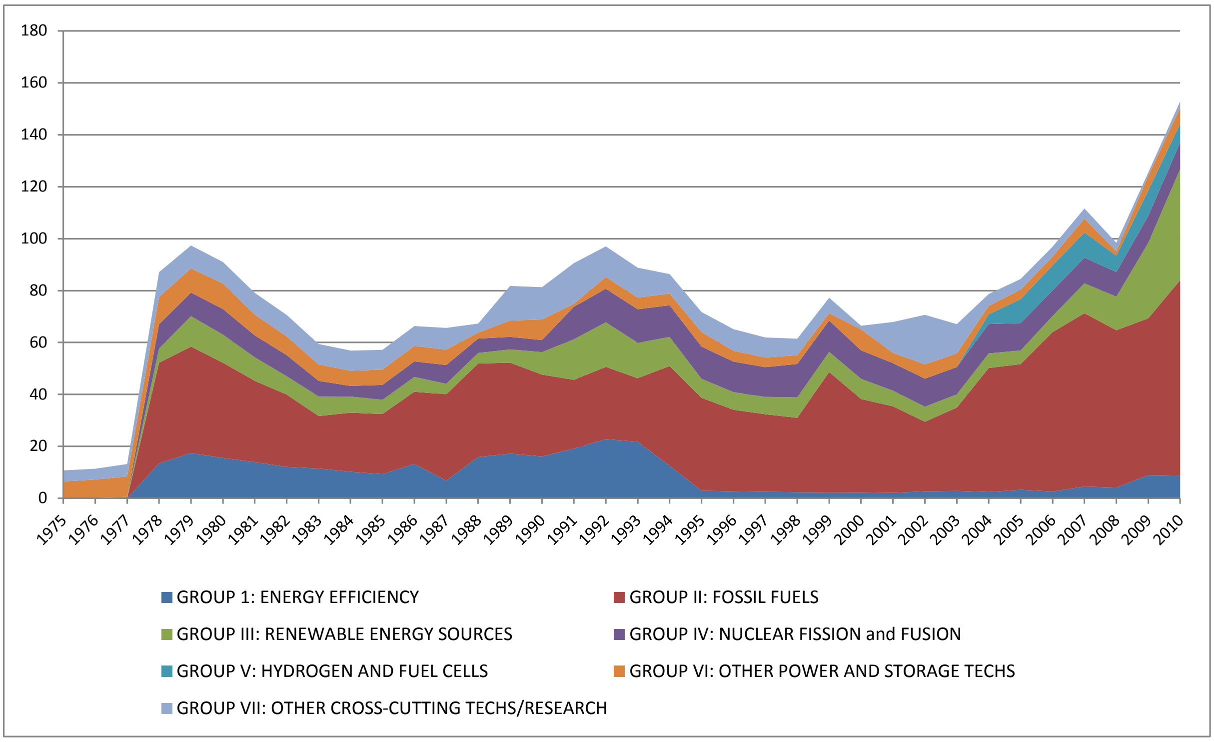



*Figure 8: Sweden, Mill. €. RD&D budgets for main groups, 1975-2010. Source: IEA*

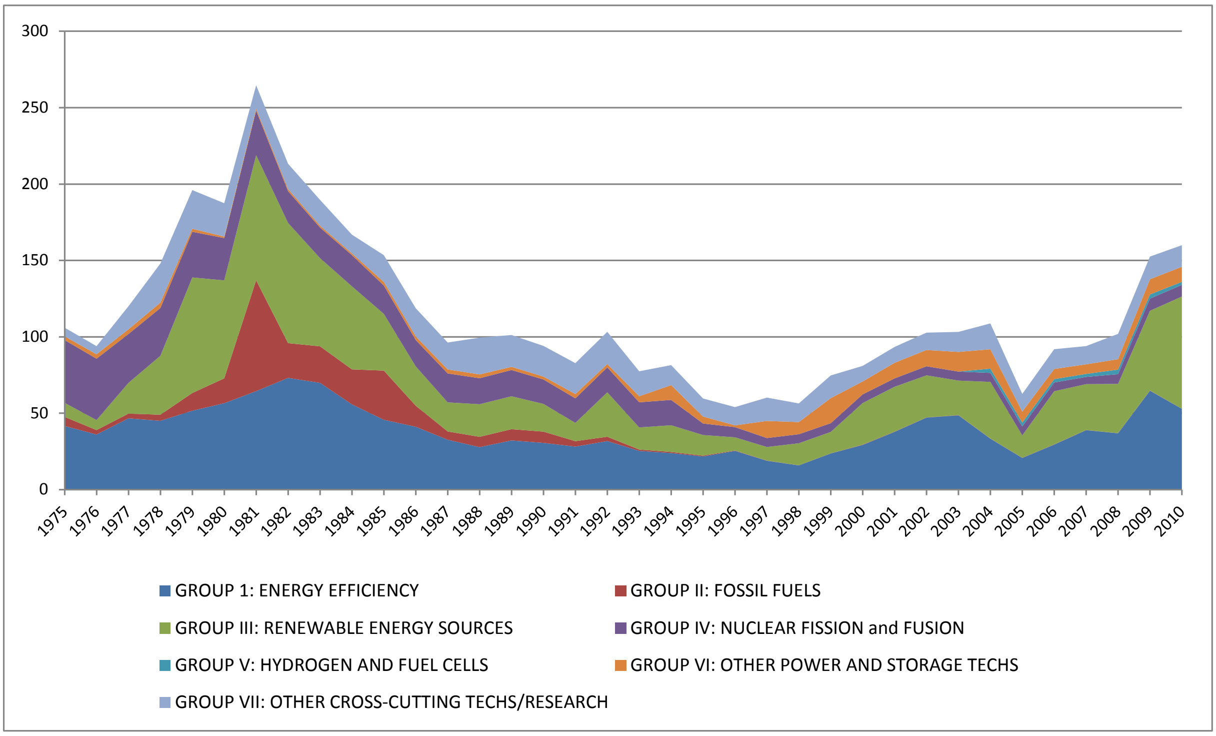
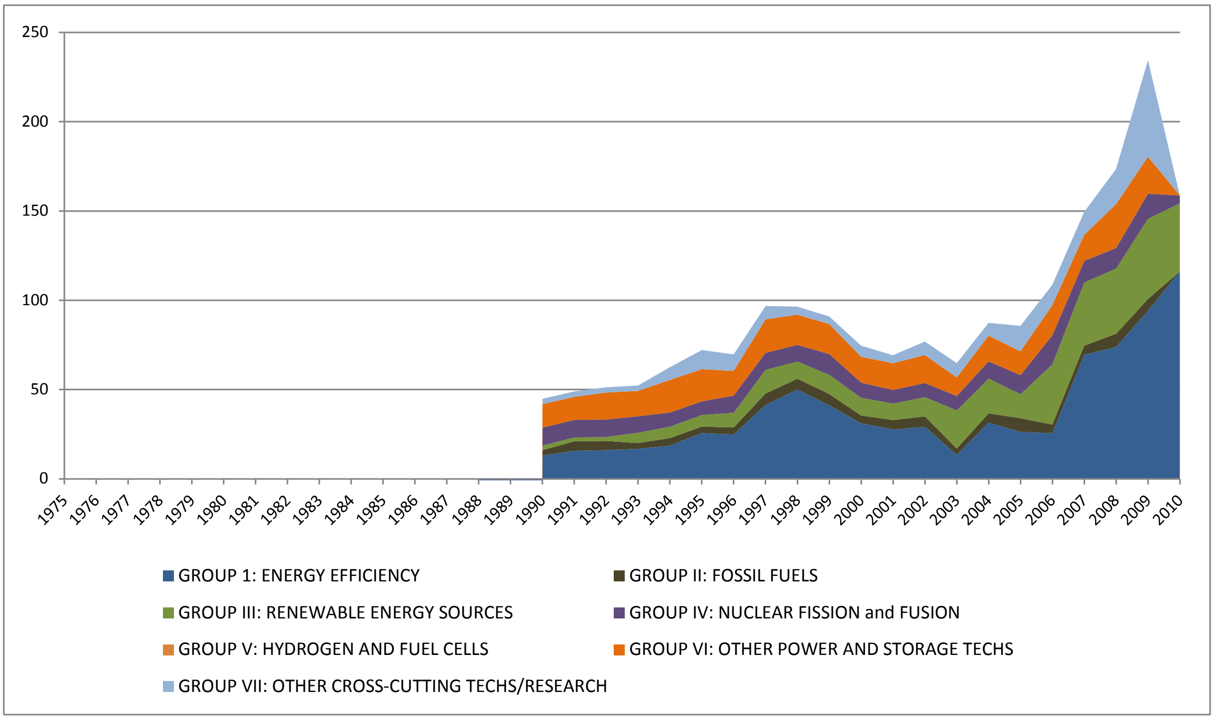


*Figure 9: Finland, Mill. €. RD&D budgets for main groups, 1990-2010. Source: IEA*




The advantage of the IEA database is that it provides public RD&D budgets by energy technologies over a relatively long time period. This means that it is possible to compare trends in budget distributions by renewable energy sources, energy efficiency areas, power and storage technologies and carbon capture and storage. The figures presented below illustrate budget developments, where some of the data is available since mid 1970's, where available upto 2010 for the energy technologies relevant for this project. The technologies are classified by the IEA in the following way:

*Table 4: Classification of (selected) energy relevant sectors in IEA RD&D statistics.*

| |
|---|
| I.1 Energy efficiency - Industry |
| I.2 Energy efficiency: Residential & commercial buildings, appliances and equipment |
| I.3 Transport |
| I.4 Other energy efficiency |
| II.3 $CO_2$ Capture and Storage |
| III.1 Solar Energy |
| III.2 Wind Energy |
| III.3 Ocean Energy |
| III.4 Biofuels (incl. liquids, solids and biogases) |
| III.5 Geothermal Energy |
| V.1 Hydrogen |
| V.2 Fuel cells |
| VI.1 Electric power conversion |
| VI.2 Electricity transmission and distribution |
| VI.3 Energy storage |

For Denmark the focus over the years was on wind energy and biofuels, while over the last years also fuel cell technology has gained substantial attention in public RD&D budgets. Energy efficiency has been addressed continuously over almost all years.

*Figure 10: Denmark, Distribution of low carbon energy RD&D budgets, Mill €. 1975-2010, Source: IEA*

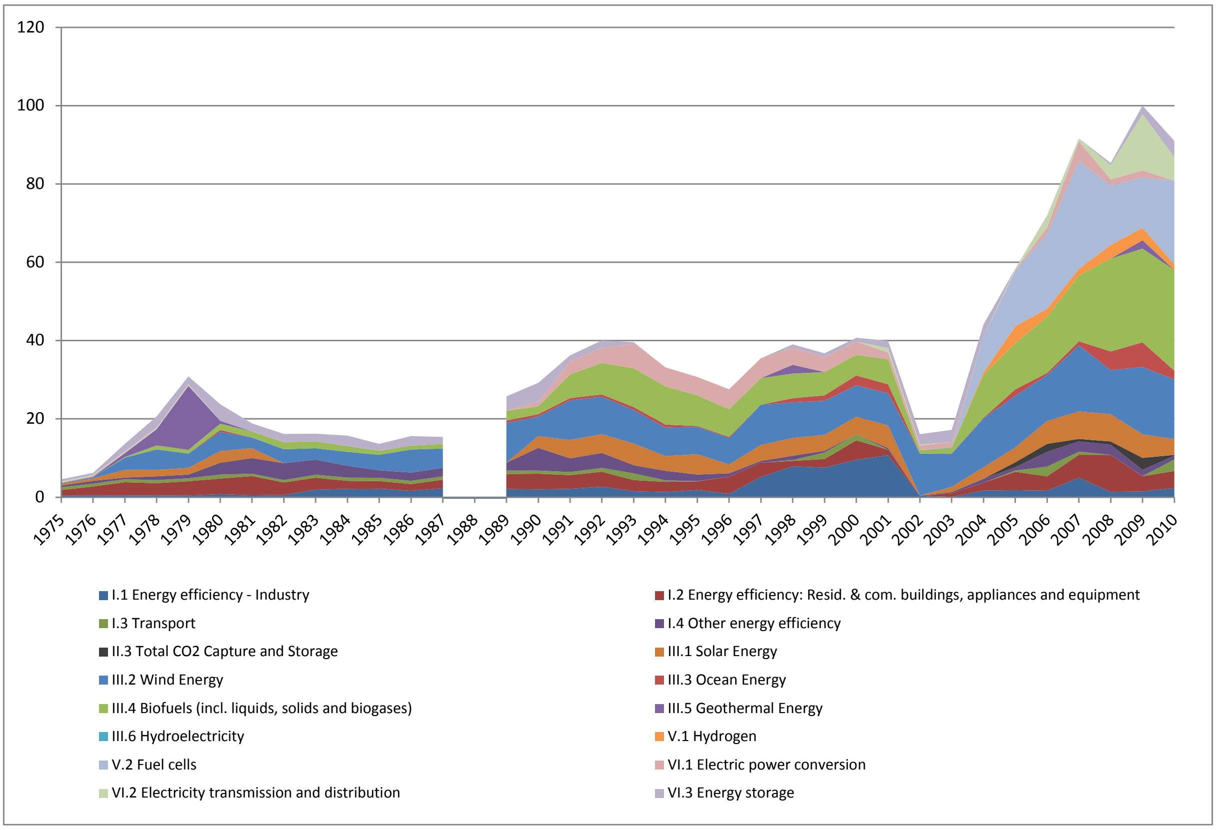
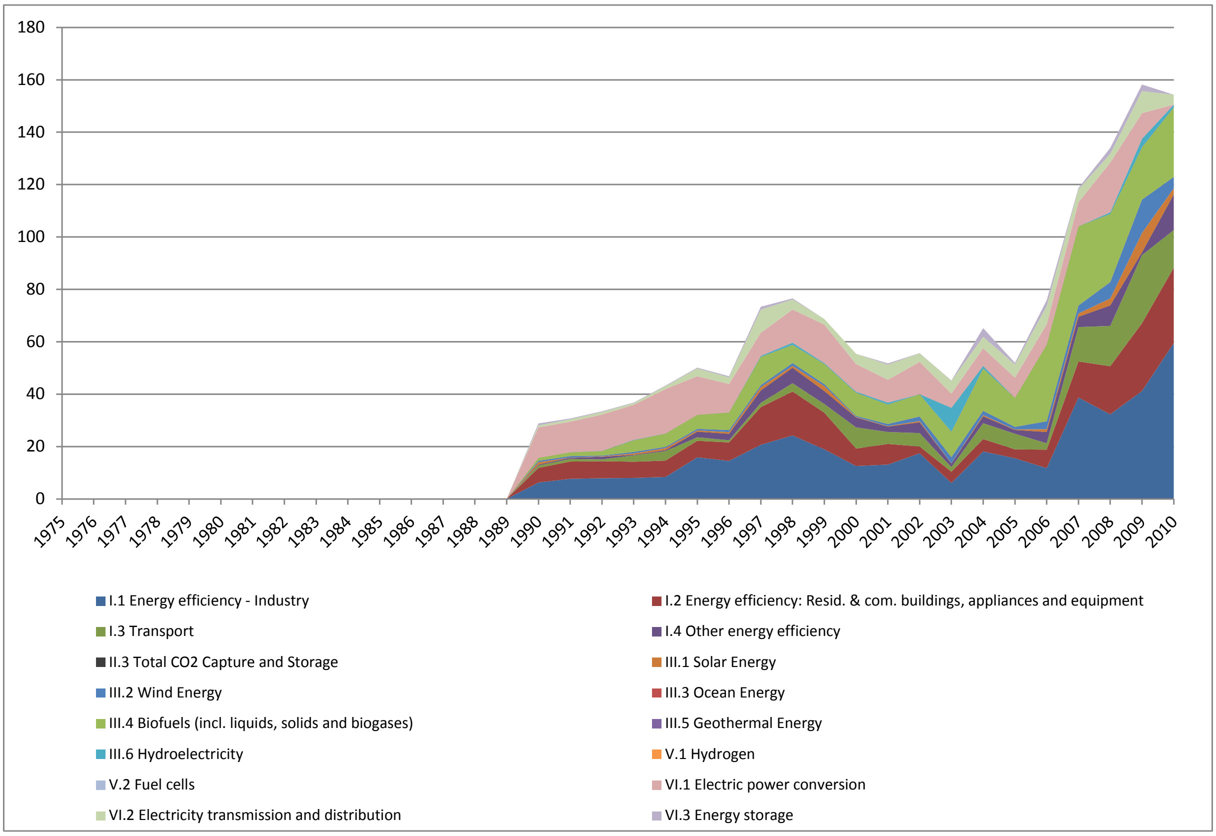
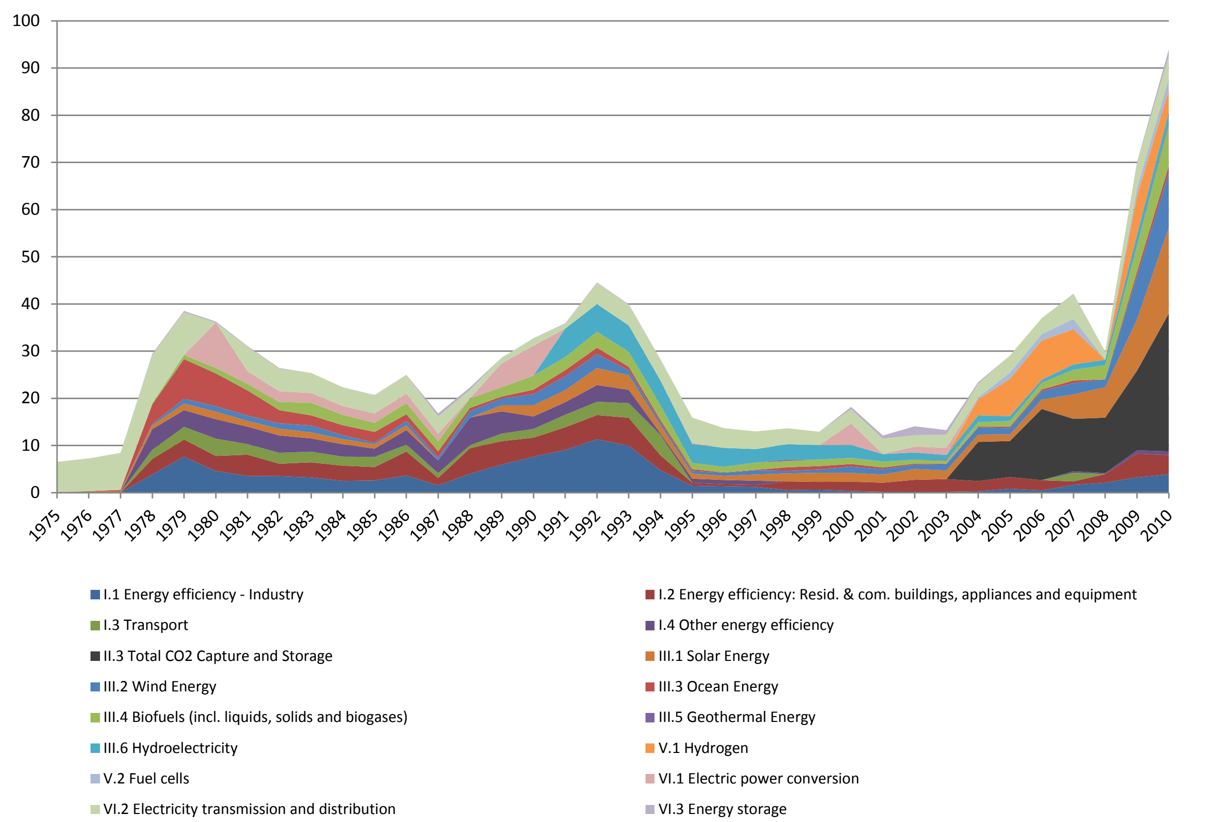



*Figure 11: Finland, Distribution of low carbon energy RD&D budgets, Mill €, 1975-2010. Source: IEA*



The public RD&D budgets of Finland have a focus on energy efficiency, as well as in industry, in residential and commercial buildings, appliances and equipment, and in transport. In the field of renewable energy sources stand biofuel highest on the agenda.

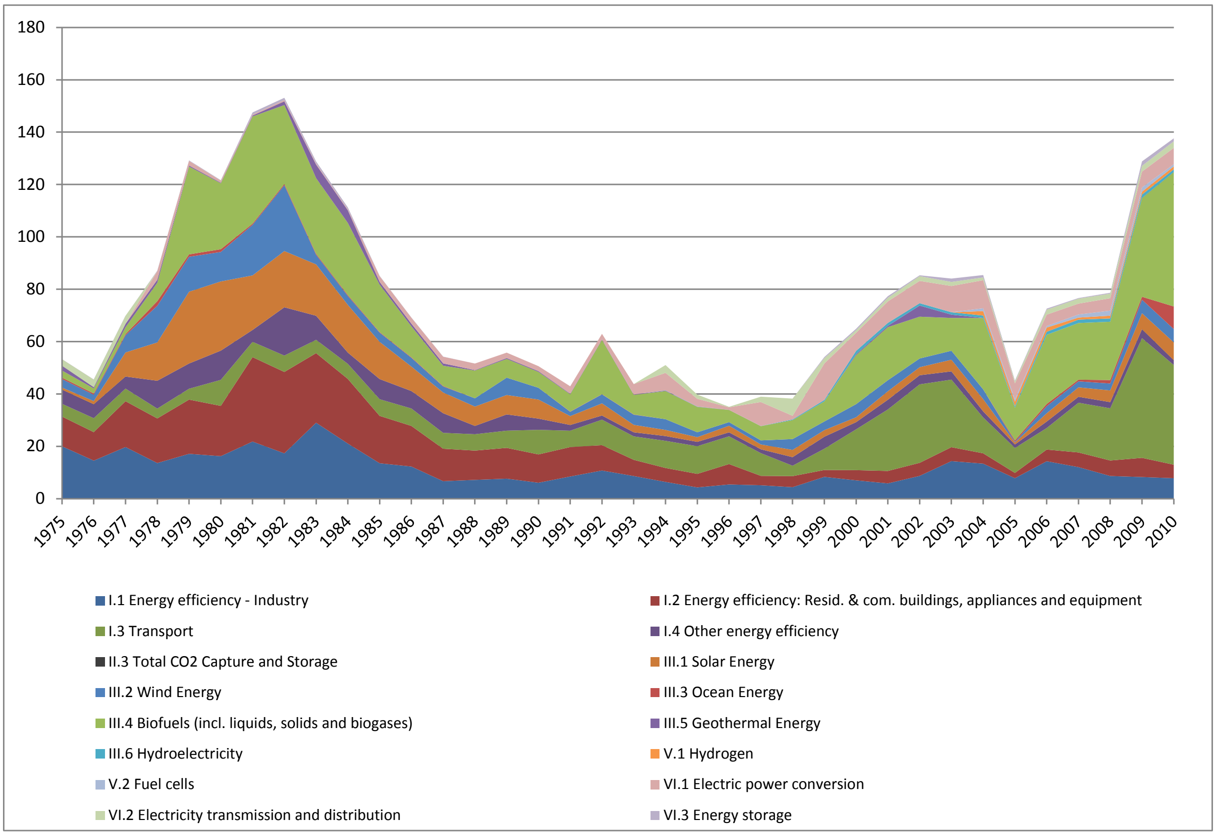
*Figure 12: Norway, Distribution of low carbon energy RD&D budgets, Mill €, 1975-2010. Source: IEA*




For Norway can be found long traditions for funding of energy efficiency in industry, but this field received much less attention from the midle of the 1990s. Carbon capture and storage has received very much funding since 2004. In the field of renewable energy solar energy, wind energy and biofuels are prioritised. RD&D on Electricity transmission and distribution, and hydrogen have been prioritised as well.

Swedish public funding of RD&D has prioritised energy efficiency as well as in industry, in residential and commercial buildings, appliances and equipment, and especially in transport. In the field of renewable energy biofuels, solar energy and wind energy were prioritised earlier, but now biofuels receive much higher funding than the two other technologies.

*Figure 13: Sweden, Distribution of low carbon energy RD&D budgets, Mill €. 1975-2010. Source: IEA*

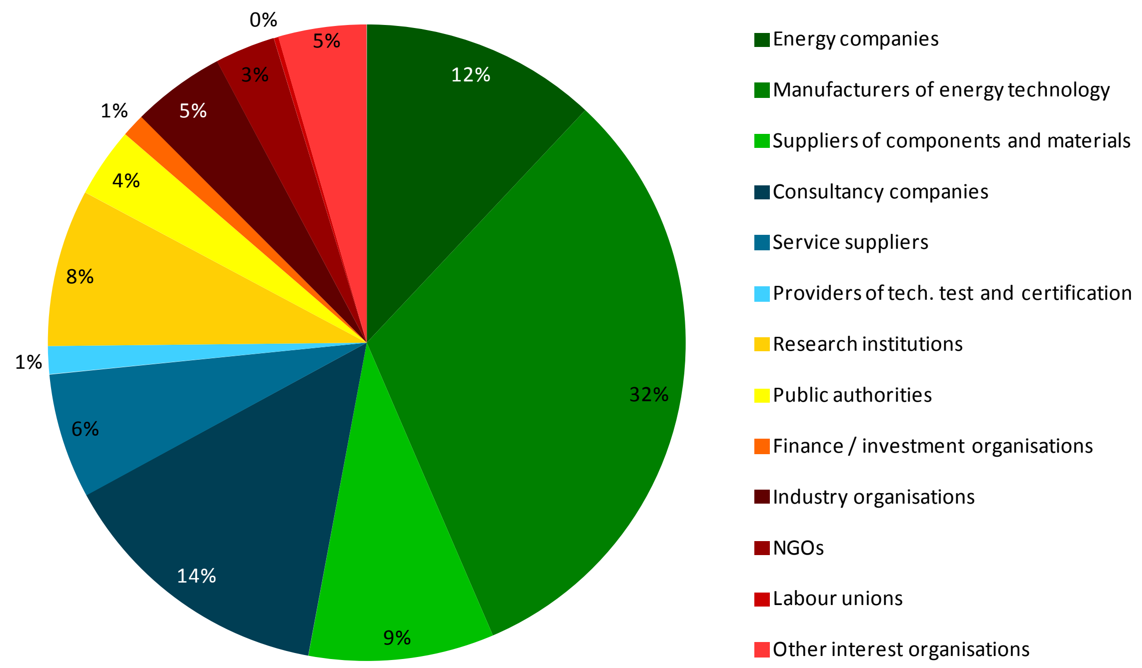



### 3.1.2 Actors

The energy innovation system consists of many different actors. It is difficult, however, to obtain a complete and 100% exact picture of the actors in the system. One reason is that there are no official databases of this and it is a difficult task to make complete lists of the actors. Another reason is that the borders of the energy innovation system to some extent are fuzzy, not only because some actors disappear over time and new actors appear, but also because some actors are influencing energy innovation in parts of their activities, but not in all their activities. They are what one might call 'part time' involved in the energy innovation system. This can for example be sub-suppliers of central, specialized components of energy technologies (e.g. suppliers of solar cell materials for solar cells systems, or suppliers of gear components for wind turbines) who sell, say, 30% of their production to the energy technology industry while the rest is sold to other industries. It can also be e.g. finance and investment organisations that in part of their activities have energy investments as a focus area, or policy makers that establish central new, regulations that influence conditions for energy innovation. Hence, there will always be a degree of uncertainty about which actors are included in the energy innovation system, and which are not.

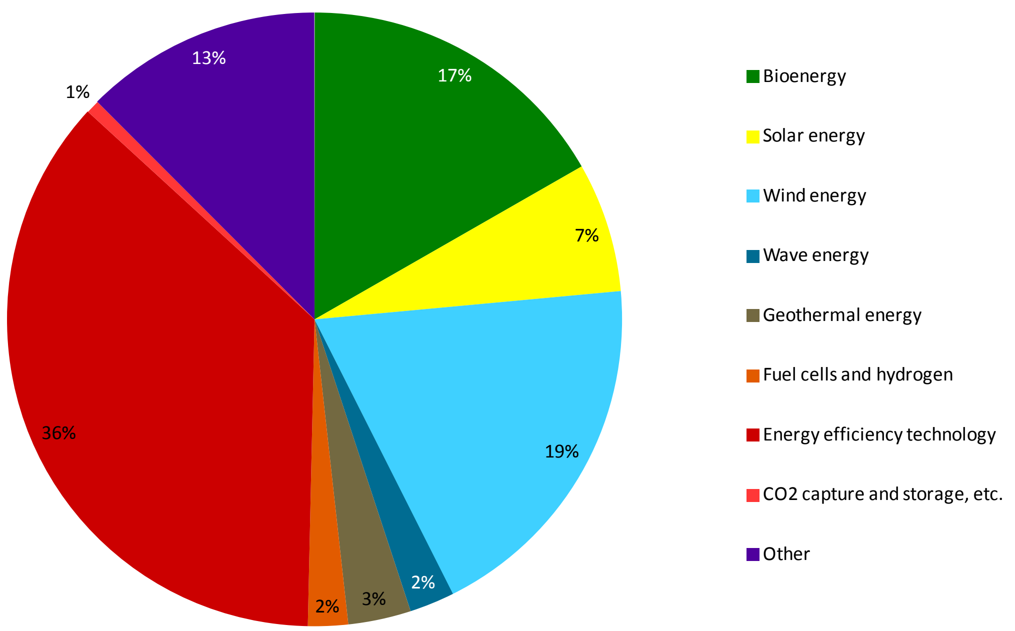
In case of the Danish energy innovation system, the 'EIS Survey of innovation activities and interaction patterns (Borup et al., 2012) can give an overview picture of the landscape of actors in relation to low-carbon technologies. According to this analysis, the energy innovation system has in the order of 1500 actors. Building on a gross list of these actors, 425 actors answered the survey's questionnaire. The results indicate a distribution of types of actors as shown in Figure 14. Around 75% of the actors are companies of different kinds. The remaining 25% are public research institutions and authorities, finance and investment actors and different types of interest organisations. Energy consumers, politicians and media organisations were not included in the survey. 12% of the actors are energy companies, including energy-net operators. Another observation is that in the order of half of the actors are companies that supply energy technologies or different types of components and services in connection to energy technology.

*Figure 14: Types of organisations, EIS Survey 2011, N=425*




The EIS survey also includes data concerning the areas of renewable and low-carbon energy technology the actors deal with, see Figure 15. Wind energy, bio energy and energy efficiency technology constitute the relatively large areas with more than hundred actors, while solar energy, geothermal energy, wave energy, fuel cells & hydrogen technology and $CO_2$ capture & storage are smaller with less than hundred actors.

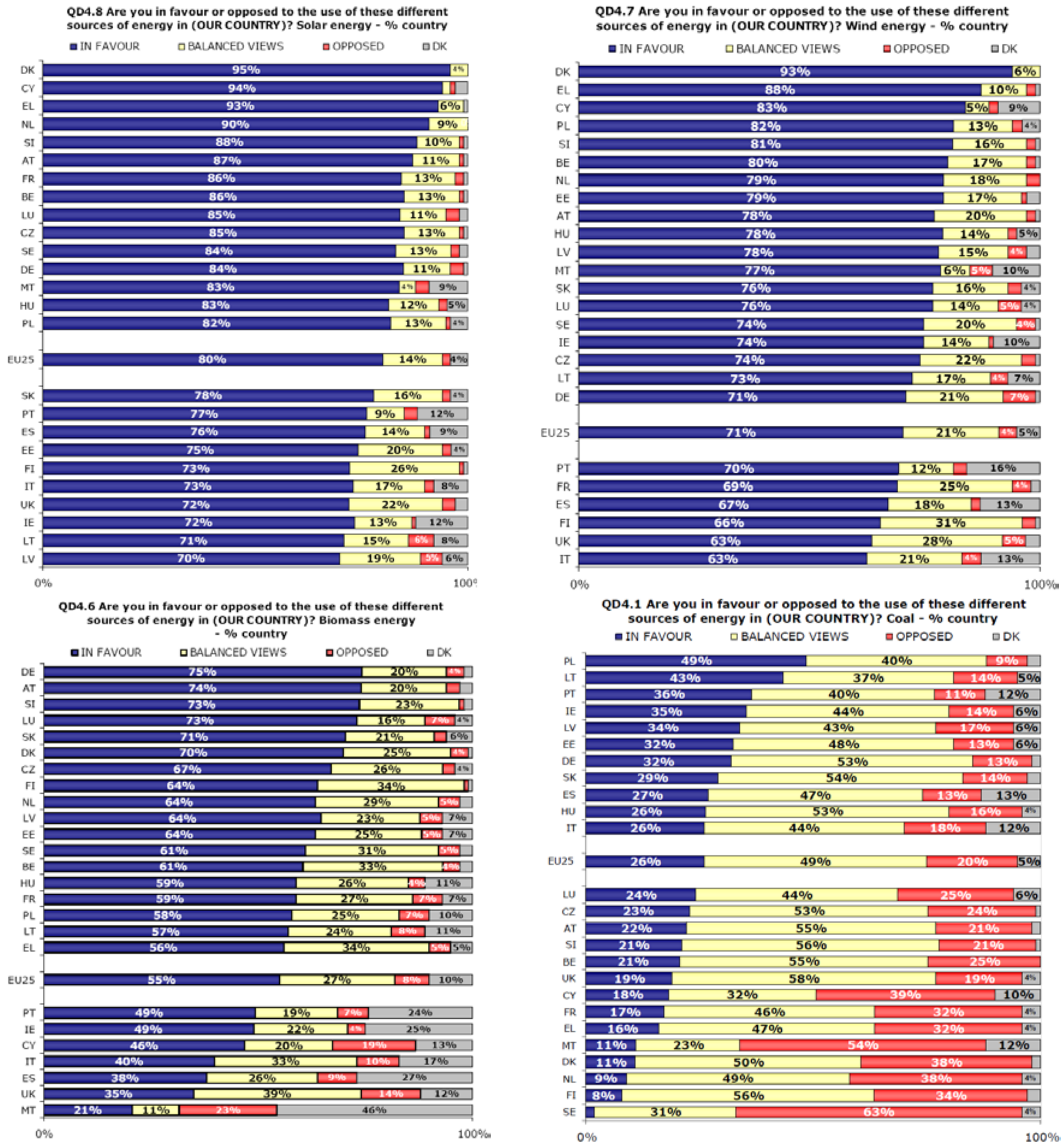
*Figure 15: Primary technology area of the organisations, EIS Survey 2011, N=425*



## 3.1.3 Public opinions

Public opinions about energy systems and different types of energy technologies indicate the general level of the conditions and 'climate' for energy innovation. More specifically, the public opinions are a measure of the general public acceptance, support and legitimacy of the different energy technologies. Data about such public opinions can be found in the European Eurobarometer surveys. The surveys are not repeated regularly, unfortunately.

*Figure 16: Public opinions in EU countries on selected energy technologies*




Source: Eurobarometer (2007)

The Eurobarometer statistics show that there are differences between the public opinions in the different EU countries, see Figure 16. The Danish population is among those most clearly in favour of renewable technologies like solar, wind and biomass energy. Moreover, they are among the populations that are most strongly opposed the use of fossil fuels like coal, despite the fact that fossil fuels are relatively much used in the Danish energy systems. It is also worth noticing that the share of 'Don't Know' answers (DK) is very small in Denmark. This is an indicator of generally high awareness about the energy technologies.

## 3.2 Throughput measures

### 3.2.1 Bibliometric – based measures for scientific publishing

Bibliometric-data is traditionally based on scientific publications and includes information on the type of publication, title, authors and their location, etc. Bibliometric data provides insight into the production of scientific literature in a given field and can be used to gauge the contributions in a given discipline by scientists working in a given country. It is possible to use also other types of data such as social media or web links, but we concentrate here on scientific publications, It is an established throughput indicator as bibliometric-based measures explore the intermediate production of the innovation process, especially those resulting at early stages of the innovation process.

Compiling and comparing data of relevant literature published by national scientists provides the basis for other indicators in addition to intermediate production of the innovation process. For example, the concentration of publication in given fields can be used as a further measure of the intensity of scientific activity; the degree of citations to given articles can be used as a measure of scientific impact; and the co-authorship patterns can be used to investigate collaboration and cooperation. The scoreboard report could not provide such data (Klitkou et al., 2010). For the purpose of this report we concentrate on the volume of publishing by technology field and on international co-authorship patterns of Danish authors.

Bibliometric data have been extracted from the ISI Web of Science of Thomson Reuters using keywords tailored to each technology field (a list is found in the annex). We propose to use the Science Citation Index and Social Science Citation Index and to include the following document types: article, editorial material, proceeding paper and review.

The application of bibliometric data hinges on the definition of keywords. We propose to apply revised search strings based on key words for each technology field as they have been developed in 2007 for the eNERGIA project (Klitkou et al., 2008a), but have been updated for this project. The keywords are used to check titles, author keywords, abstracts and keywords added by the database provider.

We use fractionalized counts of publications. This means that every paper counts only once and different author addresses receive their respective share of this paper. If the article lists two addresses then each address receives 0.5 points, for three addresses every address receives 1/3 points a. s. o.

There are also potential limitations to the use of this type of data. The delineation is also important here, because in several fields it is necessary to avoid many ‘false friends’, such as both in wind energy and solar photovoltaics many articles would stem from astrophysics.

*Table 5: Scientific publishing 2007-2010. Sources: ISI Web of Science. Based on fractionalized counts.*

| | 2nd generation bio-fuels | Fuel cells | Photovoltaic | Wind |
|---|---|---|---|---|
| Denmark | 121,3 | 148,9 | 299,3 | 318,8 |
| Finland | 75,2 | 56,4 | 496,0 | 62,8 |
| Norway | 36,1 | 71,9 | 203,4 | 95,6 |
| Sweden | 157,3 | 0,8 | 853,7 | 152,5 |
| Iceland | 4,8 | 99,8 | 3,4 | 0,8 |

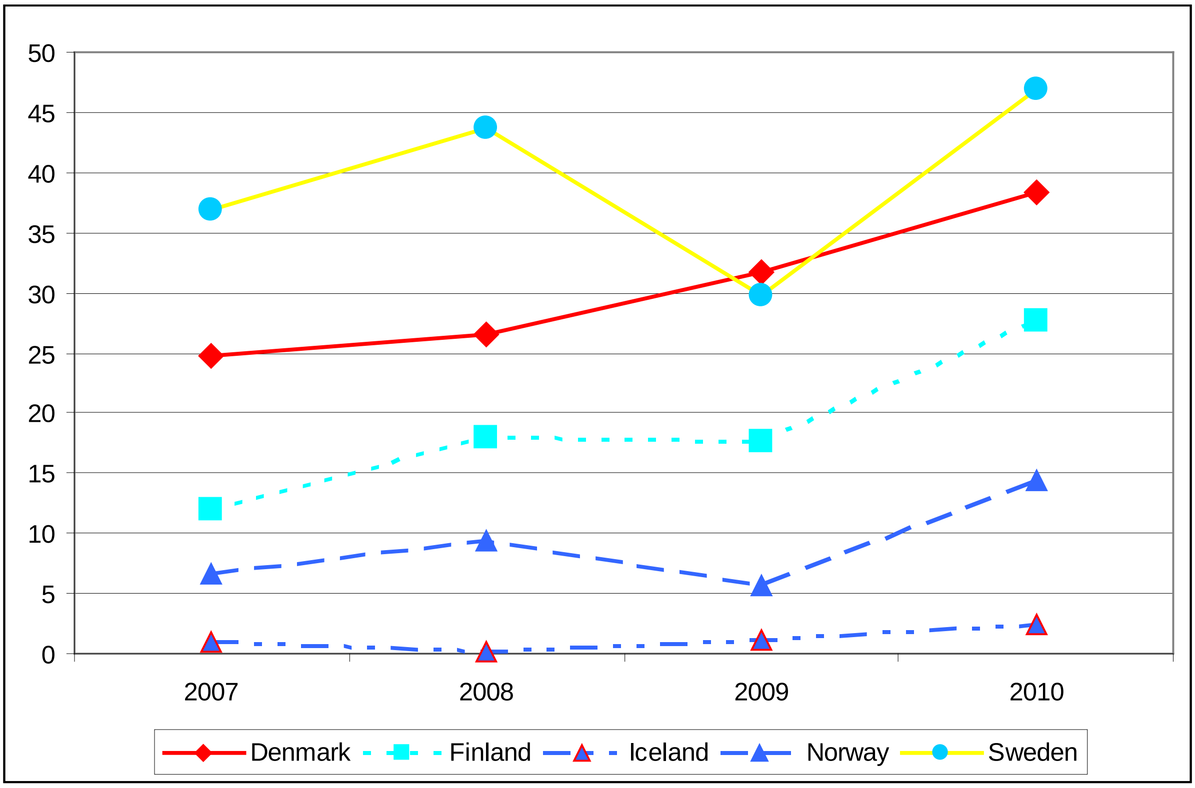
Note: Included document types: article, review, proceeding paper, editorial material.

Table 6: 2nd Generation bio-fuels: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=509).

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| Denmark (N=155) | 24,8 | 26,5 | 31,7 | 38,4 | 121,3 |
| Finland (N=98) | 11,9 | 18,0 | 17,7 | 27,6 | 75,2 |
| Iceland (N=7) | 1,0 | 0,2 | 1,1 | 2,5 | 4,8 |
| Norway (N=46) | 6,7 | 9,3 | 5,7 | 14,5 | 36,1 |
| Sweden (N=217) | 36,8 | 43,7 | 29,8 | 46,9 | 157,3 |
| Total (N=509) | 81,2 | 97,7 | 86,0 | 129,9 | 394,8 |

Note: Total counts in parentheses.

*Figure 17: 2nd Generation bio-fuels: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=509).*




Authors with at least one Danish address published 155 articles on 2nd generation (2G) biofuels, 54 or 35% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the US (Table 7.)

*Table 7: Top 10 countries Denmark co-published with in 2G bio-fuels. Based on fractionalized counts (N=54).*

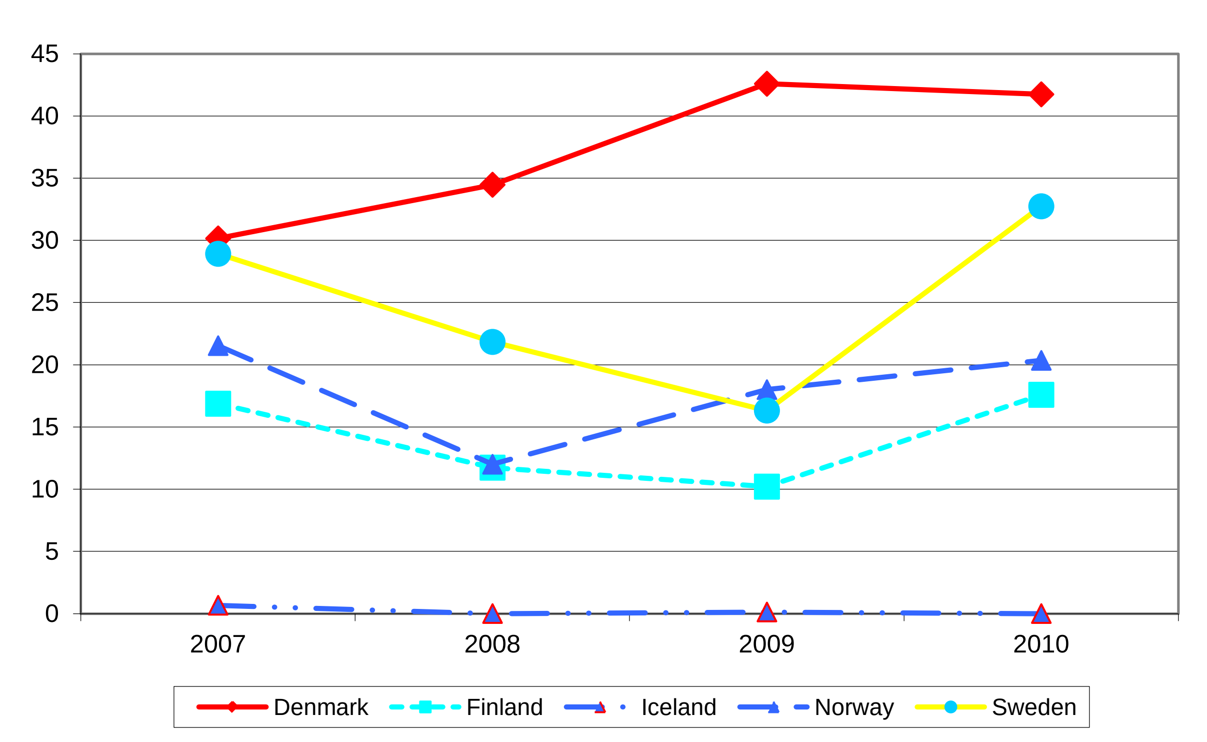
| Sum of fractionised shares | Top 10 countries |
|---|---|
| 4,2 | USA |
| 3,4 | Greece |
| 2,5 | Cuba |
| 2,4 | France |
| 2,4 | Spain |
| 2,0 | Peoples R China |
| 1,8 | Sweden |
| 1,8 | Germany |
| 1,2 | UK |
| 1,2 | Austria |

*Table 8: Fuel cells: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=494).*

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| Denmark (N=185) | 30,2 | 34,5 | 42,6 | 41,7 | 148,9 |
| Finland (N=77) | 16,9 | 11,7 | 10,2 | 17,6 | 56,4 |
| Iceland (N=2) | 0,7 | 0 | 0,1 | 0 | 0,8 |
| Norway (N=99) | 21,5 | 12,0 | 18,0 | 20,3 | 71,9 |
| Sweden (N=157) | 28,9 | 21,8 | 16,3 | 32,7 | 99,8 |
| Total | 98,1 | 80,0 | 87,2 | 112,4 | 377,8 |

Note: Total counts in parentheses.

*Figure 18: Fuel cells: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=494).*




Authors with at least one Danish address published 185 articles on fuel cells, 65 or 35% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the US (Table 9).

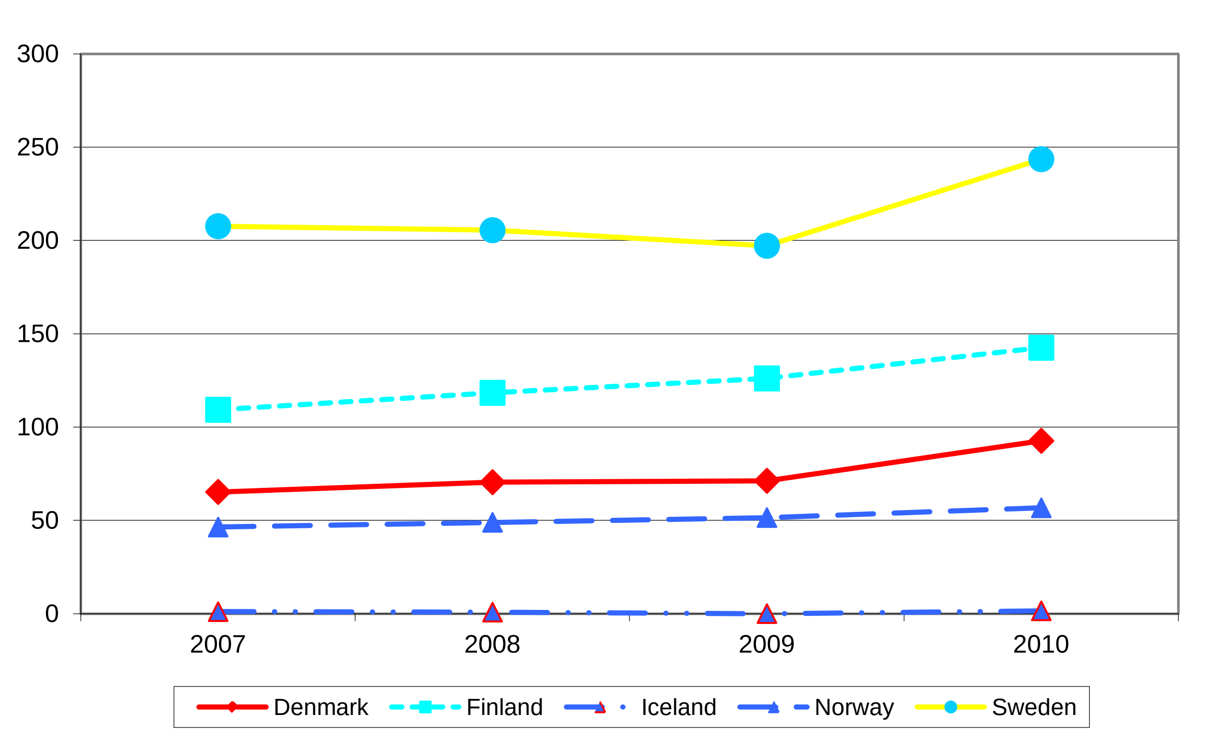
*Table 9: The top 10 countries Denmark is co-publishing with in fuel cells. Based on fractionalized counts (N=65).*

| Sum of fractionised shares | Top 10 countries |
|---|---|
| 6,5 | USA |
| 5,4 | Switzerland |
| 5,3 | Germany |
| 4,6 | Peoples R China |
| 2,9 | France |
| 2,5 | Finland |
| 2,5 | Sweden |
| 1,2 | South Korea |
| 0,8 | Netherlands |
| 0,7 | Iceland |

*Table 10: Photovoltaic: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=2565).*

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| Denmark (N=414) | 65,2 | 70,4 | 71,2 | 92,6 | 299,3 |
| Finland (N=691) | 109,2 | 118,3 | 126,0 | 142,5 | 496,0 |
| Iceland (N=7) | 1,1 | 0,8 | 0 | 1,5 | 3,4 |
| Norway (N=297) | 46,4 | 48,9 | 51,5 | 56,7 | 203,4 |
| Sweden (N=1253) | 207,6 | 205,5 | 197,1 | 243,5 | 853,7 |
| Total | 429,4 | 443,9 | 445,7 | 536,8 | 1855,8 |

*Figure 19: Photovoltaic: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=2565).*




Authors with at least one Danish address published 414 articles on photovoltaic energy, 197 or 48% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the US (Table 11).

*Table 11: The top 10 countries Denmark is co-publishing with in photovoltaic energy. Based on fractionalized counts (N=197).*

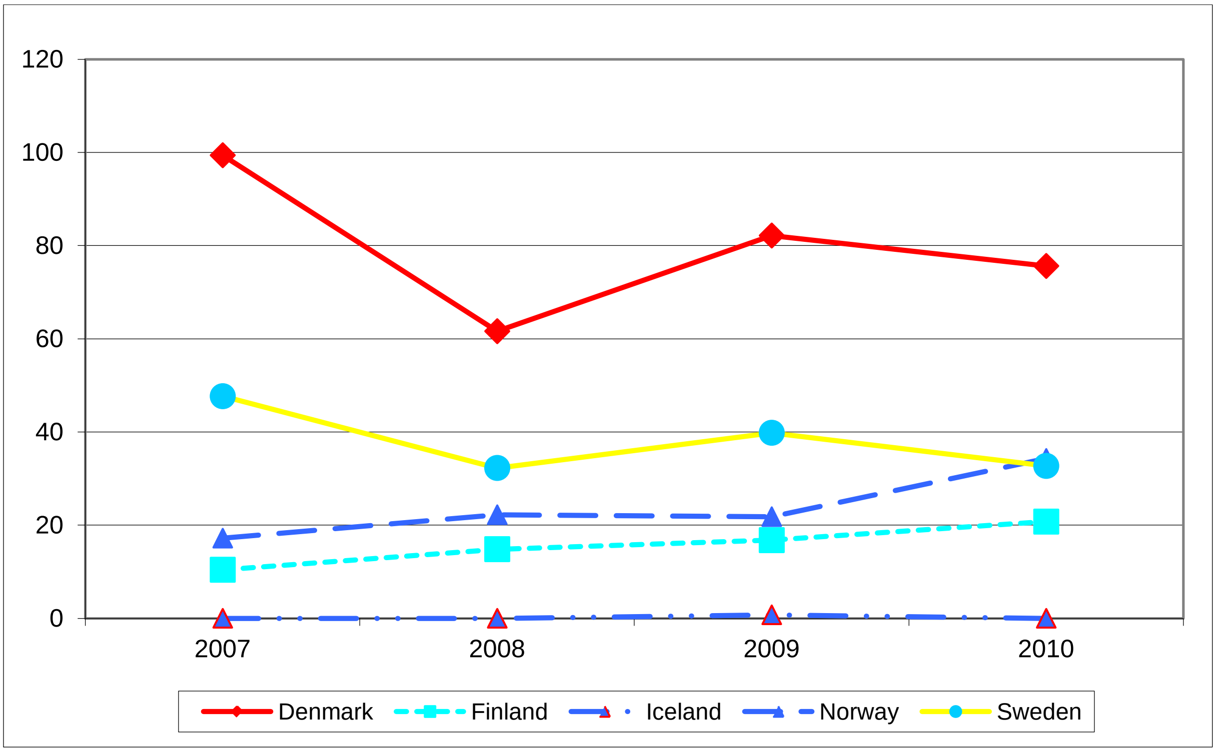
| Sum of fractionised shares | Top 10 countries |
|---|---|
| 21,5 | Germany |
| 13,8 | USA |
| 8,9 | UK |
| 7,5 | Peoples R China |
| 7,1 | Spain |
| 6,3 | Sweden |
| 4,8 | Switzerland |
| 4,3 | France |
| 3,5 | Norway |
| 3,3 | Australia |

Table 12: Wind energy: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=736).

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| Denmark (N=380) | 99,4 | 61,6 | 82,2 | 75,6 | 318,8 |
| Finland (N=80) | 10,4 | 14,8 | 16,8 | 20,8 | 62,8 |
| Iceland (N=1) | 0 | 0 | 0,8 | 0 | 0,8 |
| Norway (N=123) | 17,2 | 22,2 | 21,8 | 34,3 | 95,6 |
| Sweden (N=187) | 47,7 | 32,3 | 39,8 | 32,7 | 152,5 |
| Total | 174,7 | 131,0 | 161,3 | 163,4 | 630,3 |

Note: Total counts in parentheses.

*Figure 20: Wind energy: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=736).*




Authors with at least one Danish address published 380 articles on wind energy, 111 or 29% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the People's Republic of China (Table 13).

*Table 13: The top 10 countries Denmark is co-publishing with on wind energy. Based on fractionalized counts (N=111).*

| Sum of fractionised shares | Top 10 countries |
|---|---|
| 7,7 | Germany |
| 7,2 | Peoples R China |
| 6,1 | USA |
| 5,2 | UK |
| 4,8 | Spain |
| 3,1 | Sweden |
| 2,5 | Ireland |
| 2,4 | Norway |
| 2,1 | Italy |
| 2,0 | Australia |

### 3.2.2 Patents and low-carbon energy technologies

Patents provide a promising proxy to capture ongoing research activity in the field of low-carbon technologies. A patent is an indication of inventive activity has yielded a technology that is new to the field and that has an assumed commercial potential. Indicators based on patenting activity can for example be used to better understand the innovative activities taking place in the private sector. It can also provide an idea of actors (by country or type) who are actively innovating in these technological areas, the degree to which they collaborate, technology transfer, etc. However, patent data do not reflect the commercialisation of the patents. Therefore they are just throughput indicators. However, there are also some challenges connected to using paten data as an indicator for innovation. Increased patenting activities of public research organisations can endanger the access to new knowledge by other firms; and the diffusion of the patented inventions may be hindered if they are not supported by patent pools and clear licensing guidelines. Too broad protection on basic inventions can discourage follow-on inventors (OECD, 2004). Other non-proprietary means of disseminating knowledge, such as standards, may contribute to innovation in a more appropriate way. The OECD study highlighted that patents play a decisive role in a few industries, such as biotechnology, drugs development, chemicals and machinery and computers, while other industry sectors use other forms of protection their intellectual property, such as “secrecy, market lead, advance on the learning curve, technological complexity and control of complementary assets” (OECD, 2004, p. 9). Low carbon energy technologies encompass rather different fields of technology: from biotechnology for producing biofuels and chemistry for carbon capture towards material science for almost all technologies. We will show that the propensity to patent is different for the different fields of technology and we assume that the role of patenting is also different. This will be a field for further research.

Using patent-data to monitor emerging technologies faces several recognised methodological challenges. A major one involves categorisation. It is difficult to accurately identify renewable energy technologies in the patent record. Since there is no one-to-one correspondence between patent classes and these technologies, different approaches have been employed to tackle the question of how to exclude irrelevant patents while including relevant patents. A complementary question is how to map patents classes as unambiguously as possible to individual technologies where there is potential overlap.

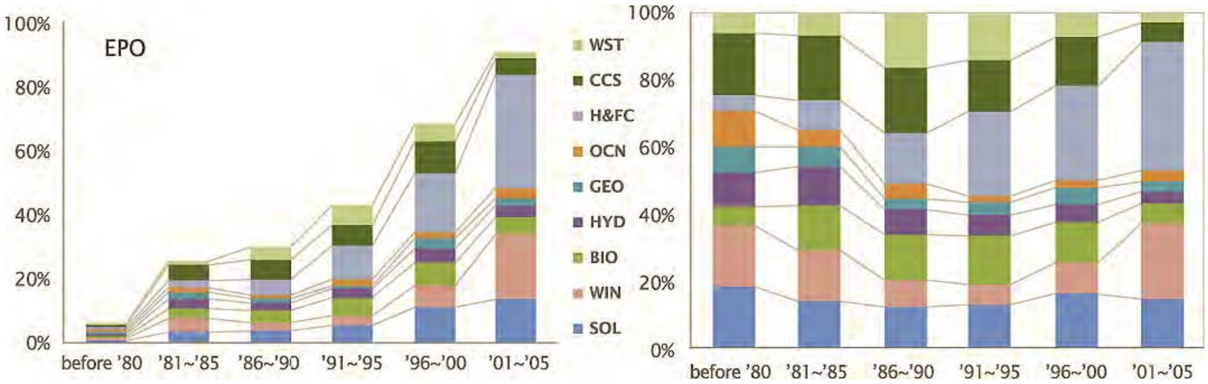
There have been several recent attempts to address these questions at the national level (e.g. the UK: Chatham House report of Lee et al., 2009), the regional level (the Nordic level: Klitkou et al., 2008a), and the international level (OECD: e.g. Johnstone and Hascic, 2009a; Johnstone et al., 2012) to name a few. The approaches generally combine targeted IPC-based searches with some form of expert verification[2]. In addition, the UK and Nordic efforts also use assignee information of known actors in the field to complement their searches. Johnstone et al. have shown that the matching of patent classes with industrial sectors based on concordances is not precise enough because often the industry developing a patent differs from the industry using the patent and this makes it unclear clear to which industrial sector a patent should be attributed (2012, p. 2159). In cases where the user of the technology and the technology providers involve different organisations and firms this can be an issue, but also when these entities have different departments specialised into different technologies. Therefore it is necessary to identify patent classes in the patent classification system for specific technologies and eventually combine them with keywords. The WIPO effort uses a comprehensive set of data (EPO, WIPO, USPTO, JPO, KIPO, SIPO). The approach is pragmatic: it combines keywords with a classification (IPC) search. There is the question of accuracy since the IPC (sub)-classes are not subjected to a verification process.

Efforts at the Nordic level have also used a combination of IPC class search with keywords. In addition the help of experts in the technological areas have been enlisted and the patent portfolios of relevant actors have been reviewed.

The eNERGIA project revealed following results on patenting for Denmark: a very high activity level in two of the selected technology fields – both wind and second generation biofuels – and in addition also in hydrogen (Klitkou et al., eNERGIA report Part 2, p. 103).

[2] WIPO combine only keywords with an IPC search.

*Figure 21: WIPO Applications at EPO by technology - Number of patent applications, claimed priorities, worldwide.*




Source: WIPO (2009) Patent-based Technology Analysis Report – Alternative Energy. p 29.

The most promising and comprehensive approach thus far comes from the EPO. One advantage of this approach is that the identification process is primarily done by the patent office. In terms of treating incoming applications, it is potentially more efficient and more accurate to identify concurrently at the patent office rather than to depend on an ex-post methodology.

The following results are based on a study with data from the (Fall 2009) version of EPO Worldwide Patent Statistical Database (PATSTAT).[3] In particular it utilizes table tls220 on which the categories are based. These categories were introduced in the 2009 version of Patstat (see below). The technological areas were initially classified as 'environmentally sound technologies'. In the subsequent versions of PATSTAT, these technologies have been re-labelled and further refined. A special thanks to Dr Konstantinos Karachalios and his colleagues at the EPO for providing data and to Pari Patel who helped extract the data. The EPO approach became available in March 2010 and uses the more detailed ECLA patent class system[4] to define technology which is systematically vetted by researchers, field experts and EPO examiners. The latest (since Fall 2009) version of PATSTAT includes the results of a comprehensive effort to identify a set of low-carbon technologies in EPO and more widely.

In 2009 the EPO started a cooperation with the UN Environment Programme (UNEP) and the International Centre on Trade and Sustainable Development (ICTSD) to produce a joint study to advance the understanding of the role of intellectual property in promoting access to Environmentally Sound Technologies (EST) and outline some of the existing and prospective measures that could be considered in support of a post-Kyoto climate regime. The study could provide useful input into ongoing discussions on technology transfer in the context of the UN Framework Convention on Climate Change (UNFCCC). The EST publications were identified in a one-off exercise in 2009 (see Figure 22 and Annex: Main EST categories for patent mapping).

The data covers European patent-applications either via the EPO or the PCT channels. The unit is the application, according to the original filing date. If desired, the patent-families could be computed. The basis of country of origin is the inventor and not the assignees. We assume that mapping of invention activities is more helpful for understanding innovation processes than mapping of assignees. The data presentation is based on fractional counting of both the patent inventor and of the technology. This accounts for cases where a single patent-application includes more than one inventor and/or its technology spans more than one category, respectively.

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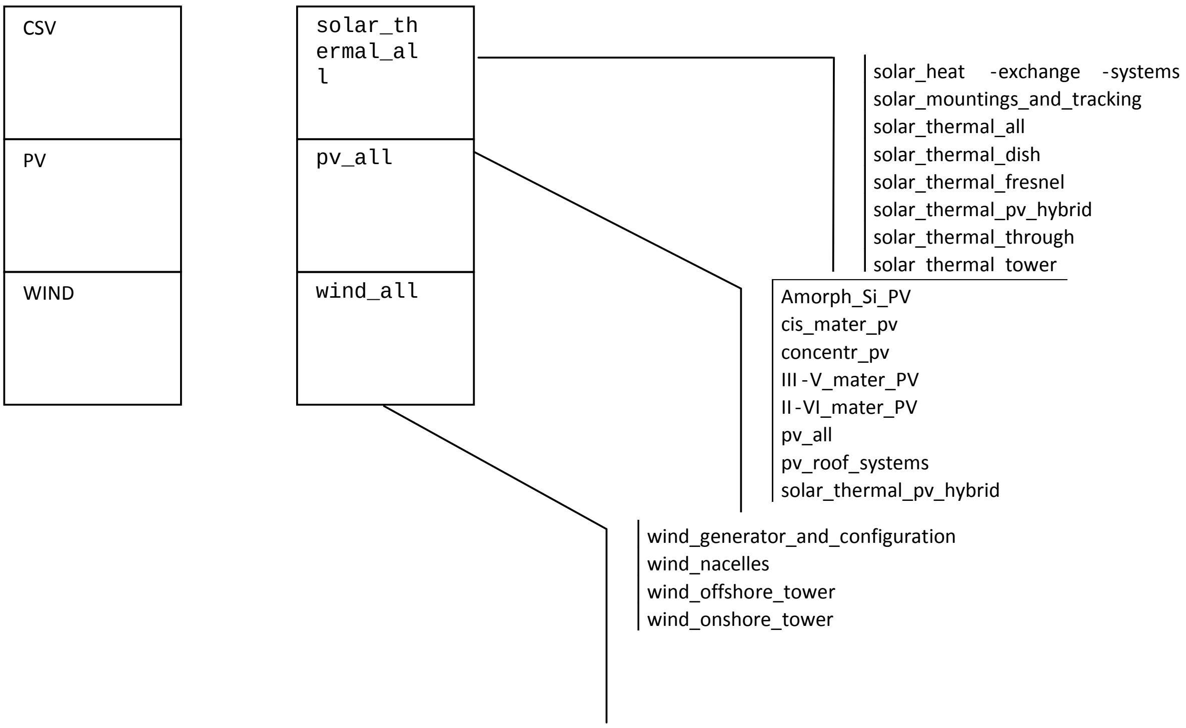
[3] http://forums.epo.org/epo-worldwide-patent-statistical-database/topic586.html

[4] See http://www.intellogist.com/wiki/ECLA_Classification_System

*Figure 22: EPO definitions of Environmentally Sound Technologies (EST)*




The following tables give the results for bio-energy, solar photovoltaic energy, wind energy, hydropower and carbon capture and storage. Results for geothermal energy have not been given because they are negligible. The results confirm identified strengths in wind and bioenergy technology in the eNERGIA study even though there only patenting for second generation biofuels was addressed and not bioenergy in general.

*Table 14: EPO applications in bio-energy. 1999-2008.*

| | Denmark | Other Nordic countries | Other EU27 | Other countries | Unknown | ***All*** |
|---|---|---|---|---|---|---|
| 1999 | 4 | 3 | 12 | 17 | 2 | ***37*** |
| 2000 | 4 | 1 | 21 | 27 | 11 | ***62*** |
| 2001 | 5 | 4 | 20 | 32 | 9 | ***65*** |
| 2002 | 3 | 6 | 25 | 41 | 9 | ***72*** |
| 2003 | 4 | 5 | 31 | 42 | 9 | ***82*** |
| 2004 | 8 | 8 | 37 | 69 | 2 | ***116*** |
| 2005 | 14 | 9 | 24 | 102 | 3 | ***142*** |
| 2006 | 10 | 6 | 60 | 126 | 6 | ***201*** |
| 2007 | 8 | 5 | 101 | 179 | 10 | ***284*** |
| 2008 | 5 | 12 | 86 | 203 | 5 | ***289*** |
| ***Total*** | ***65*** | ***59*** | ***415*** | ***835*** | ***65*** | ***1 349*** |

*Table 15: EPO applications in solar photovoltaic energy. 1999-2008.*

| | Denmark | Other Nordic countries | Other EU27 | Other countries | Unknown | ***All*** |
|---|---|---|---|---|---|---|
| 1999 | 0 | 7 | 59 | 148 | 27 | ***236*** |
| 2000 | 1 | 6 | 105 | 190 | 42 | ***338*** |
| 2001 | 1 | 5 | 97 | 185 | 48 | ***328*** |
| 2002 | 0 | 2 | 105 | 204 | 88 | ***395*** |
| 2003 | 1 | 1 | 118 | 261 | 77 | ***448*** |
| 2004 | 0 | 7 | 167 | 372 | 30 | ***551*** |
| 2005 | 1 | 7 | 153 | 425 | 35 | ***602*** |
| 2006 | 1 | 12 | 232 | 477 | 36 | ***724*** |
| 2007 | 2 | 11 | 262 | 565 | 51 | ***856*** |
| 2008 | 1 | 7 | 319 | 660 | 57 | ***999*** |
| ***Total*** | ***8*** | ***65*** | ***1618*** | ***3 486*** | ***490*** | ***5 475*** |

*Table 16: EPO applications in wind energy. 1999-2008.*

| | Denmark | Other Nordic countries | Other EU27 | Other countries | Unknown | ***All*** |
|---|---|---|---|---|---|---|
| 1999 | 16 | 6 | 35 | 13 | 4 | ***73*** |
| 2000 | 14 | 7 | 66 | 40 | 6 | ***130*** |
| 2001 | 14 | 10 | 90 | 35 | 11 | ***157*** |
| 2002 | 24 | 15 | 146 | 54 | 7 | ***241*** |
| 2003 | 47 | 9 | 128 | 62 | 14 | ***256*** |
| 2004 | 36 | 9 | 129 | 96 | 6 | ***264*** |
| 2005 | 43 | 7 | 134 | 118 | 4 | ***300*** |
| 2006 | 43 | 17 | 151 | 147 | 4 | ***346*** |
| 2007 | 95 | 16 | 231 | 201 | 4 | ***521*** |
| 2008 | 80 | 24 | 245 | 207 | 6 | ***536*** |
| ***Total*** | ***412*** | ***117*** | ***1 355*** | ***972*** | ***63*** | ***2 822*** |

*Table 17: EPO applications in hydropower. 1999-2008.*

| | Denmark | Other Nordic countries | Other EU27 | Other countries | Unknown | ***All*** |
|---|---|---|---|---|---|---|
| 1999 | 2 | 5 | 29 | 16 | 5 | ***55*** |
| 2000 | 3 | 7 | 28 | 34 | 7 | ***76*** |
| 2001 | 3 | 4 | 40 | 22 | 4 | ***71*** |
| 2002 | 3 | 13 | 32 | 37 | 7 | ***90*** |
| 2003 | 1 | 7 | 46 | 46 | 13 | ***110*** |
| 2004 | 6 | 18 | 53 | 71 | 2 | ***149*** |
| 2005 | 0 | 14 | 62 | 93 | 4 | ***166*** |
| 2006 | 3 | 14 | 60 | 98 | 3 | ***177*** |
| 2007 | 2 | 22 | 96 | 136 | 4 | ***253*** |
| 2008 | 3 | 15 | 106 | 124 | 3 | ***247*** |
| **Total** | **26** | **116** | **550** | **676** | **50** | ***1 393*** |

*Table 18: EPO applications in carbon capture and storage. 1999-2008.*

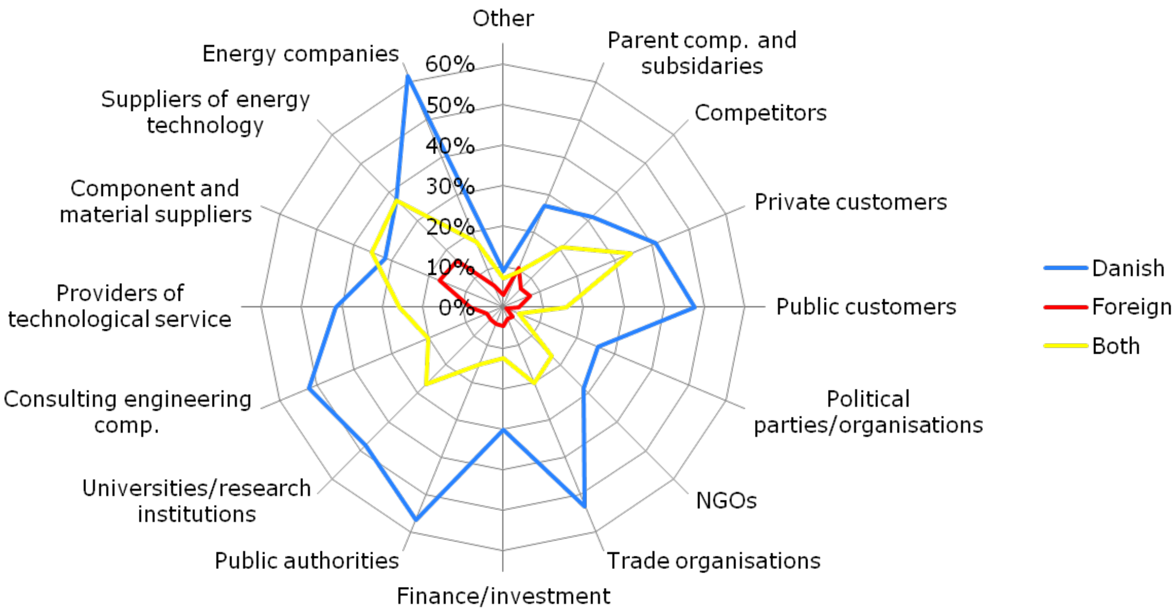
| | Denmark | Other Nordic countries | Other EU27 | Other countries | Unknown | ***All*** |
|---|---|---|---|---|---|---|
| 1999 | 0 | 1 | 15 | 22 | 8 | ***44*** |
| 2000 | 0 | 3 | 20 | 42 | 17 | ***80*** |
| 2001 | 0 | 3 | 20 | 28 | 16 | ***65*** |
| 2002 | 1 | 3 | 15 | 31 | 22 | ***68*** |
| 2003 | 1 | 3 | 21 | 37 | 12 | ***69*** |
| 2004 | 1 | 6 | 18 | 52 | 2 | ***73*** |
| 2005 | 2 | 6 | 23 | 56 | 4 | ***83*** |
| 2006 | 1 | 11 | 47 | 84 | 4 | ***139*** |
| 2007 | 0 | 11 | 52 | 108 | 3 | ***167*** |
| 2008 | 3 | 9 | 61 | 117 | 2 | ***174*** |
| ***Total*** | ***9*** | ***56*** | ***290*** | ***575*** | ***89*** | ***961*** |

### 3.2.3 Cooperation and interaction

Patterns of cooperation and interaction are measured in the EIS survey (Borup et al., 2012). The following figure shows the pattern of cooperation with respect to which types of actors there is cooperation with concerning energy technology development. The period considered is 2010-2011. For example, more than 60% of the actors in the Danish energy innovation system had cooperation with Danish energy companies.

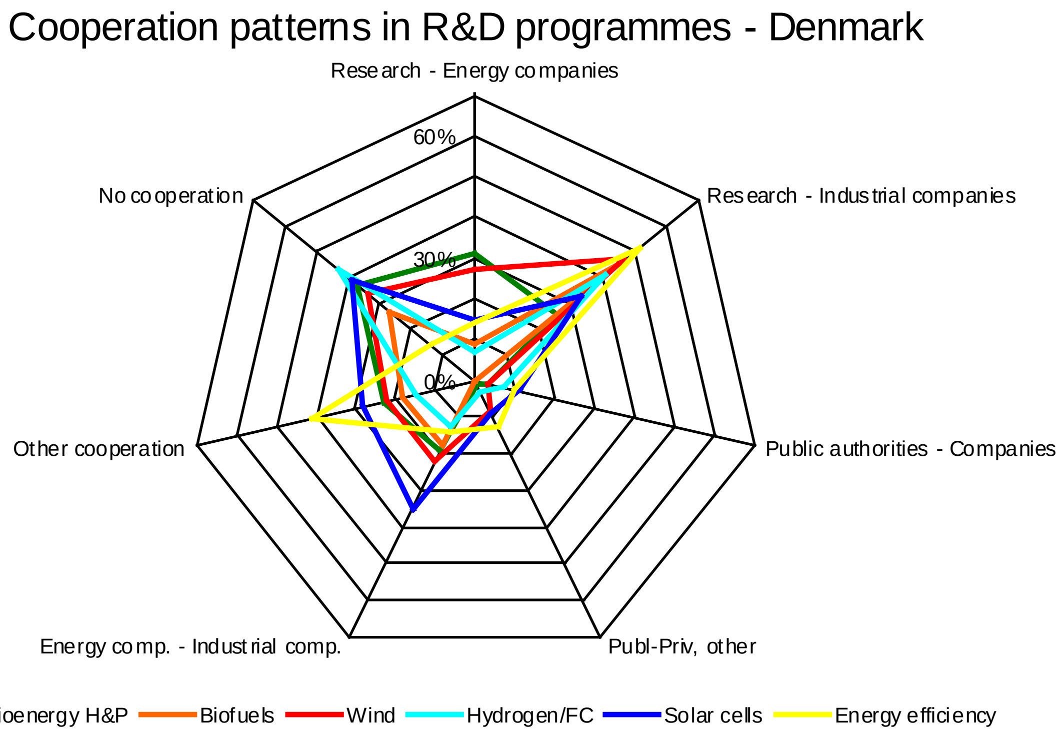
Moreover, the figure shows to what degree the actors participate in cooperation activities with domestic partners, cooperation with partners from abroad, or both. Hence it is also a measure of how large a share of the cooperation in the energy innovation system that is internal Danish interaction and how large a share that is international interaction. The results show that a large share of cooperation relations is internal Danish interaction, while only a smaller share is international.

*Figure 23: Pattern of cooperation in Danish energy innovation, type of cooperation partners over the two-year period 2010-2011, Danish or foreign partners, EIS Survey 2011, N=391*



Cooperation patterns in publicly funded R&D activities can be measured by analysis of project participants in the projects in the public R&D programmes on energy (Borup et al., 2008). The analysis builds on the DENP database supplemented with additional material about projects and participating organisations. In the analysis attention is given primarily to public-private and other cross-going cooperation. The results in different areas of energy technology are shown in the following figure. It can be seen that the cooperation pattern in the publicly funded R&D activities varies between the different technology areas. A considerable amount of projects include public-private cooperation in the sense of cooperation between research institutions and industrial companies. Compared to this, the share of projects with cooperation between research institutions and energy companies is smaller. This is the case in all the covered technology areas apart from bioenergy for heat & power.

*Figure 24: Cooperation pattern in the public energy R&D programmes in Denmark. Share of projects with cross-going cooperation between actors of different type. Running projects 2007-2008. N=492.*



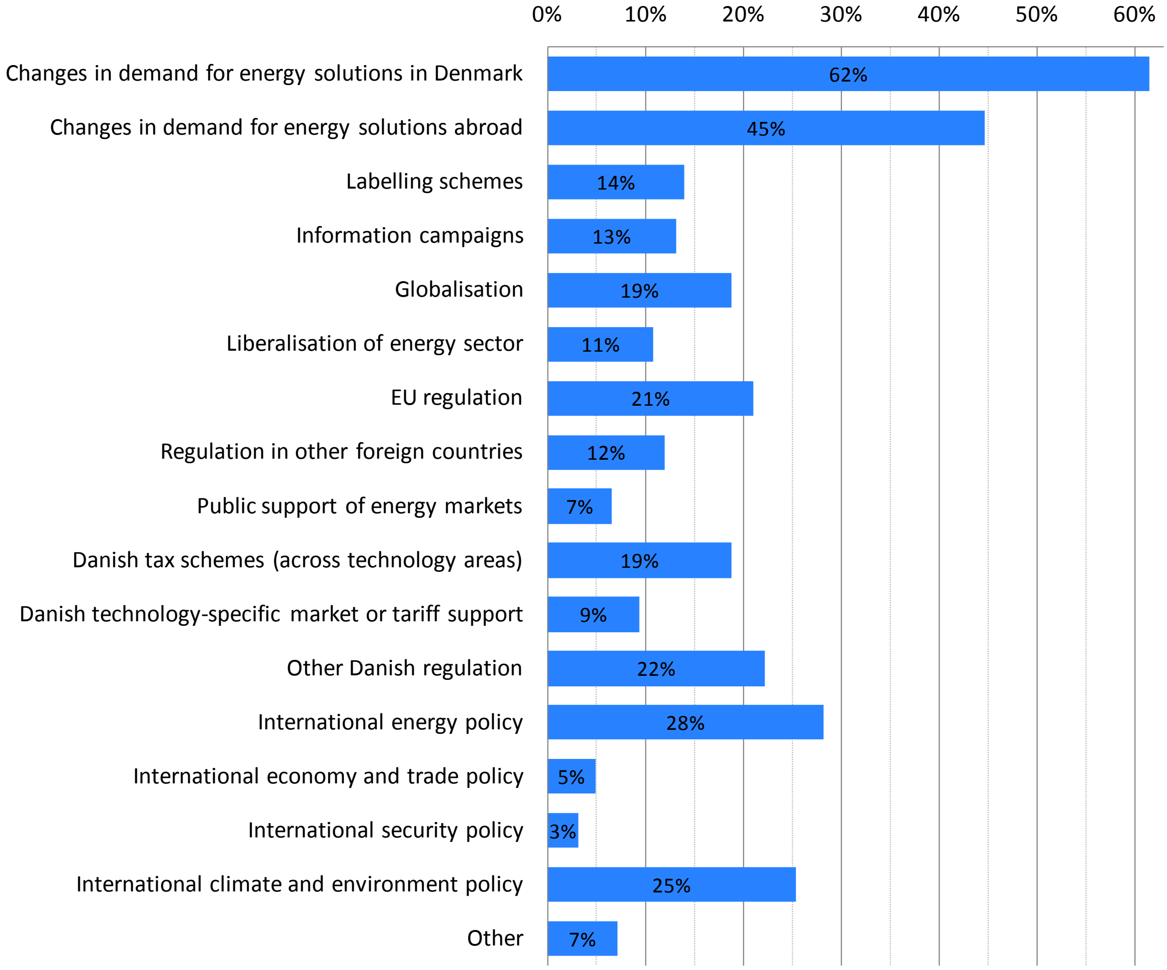

Source: Borup et al. 2008.
Notes: The figure shall be read clockwise, starting from 12 o'clock. Biofuels are here defined as biomass based liquid fuels for transportation purposes.

The figure also shows that the majority of projects contain some kind of cross-going cooperation; 'No cooperation' is less than 50% of the projects. This finding is especially significant within energy efficient technology where less than 15% of the projects have no cross-going cooperation, i.e., there is cross-going cooperation in more than 85% of the projects.

### 3.2.4 Market developments as driving factor for innovation

Developments in market demands can be an important driving factor for innovation. This type of through-put indicator is analysed in the EIS Survey (Borup et al., 2012) where amongst other things the sources of the market developments in the recent years (2009-2011) are illuminated, building on identification by the involved actors in the Danish energy innovation system. The majority of the actors (2/3) experienced a significant development in the market in connection to their activities on energy technology development. The sources of the market developments are identified as shown in the following figure. It can be seen that developments in demand on the domestic Danish market are more important than developments on foreign markets. Of the more specific sources behind the market changes, the international policies on energy and on climate and environmental are the most important, followed by developments in regulation on Danish and EU level.

*Figure 25: The sources of market developments as driving factor for innovation. (Share of actors that experienced the different sources.) EIS Survey 2011, N=351*



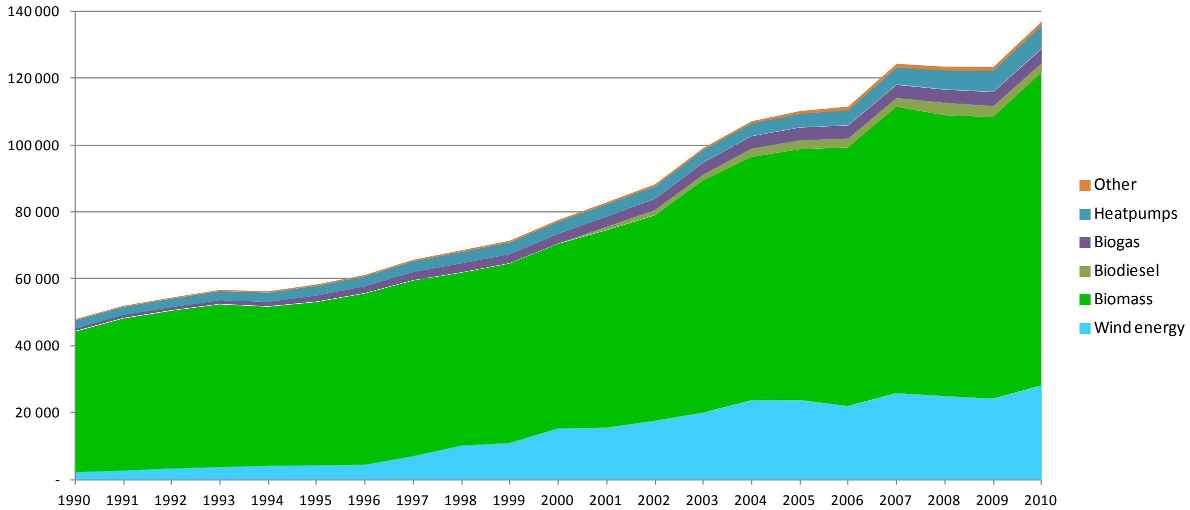
## 3.3 Output measures

### 3.3.1 Application of low carbon technologies – domestic use

Market application of new low-carbon technologies and products is among the most direct indicators of output from the energy innovation system. It can be measured in economic terms as it is done in the exports and trade statistics shown later. Or it can be measured in technical terms, e.g., in the amounts of products sold or, in the amount of installed energy production effect in the energy systems, the amount of energy produced by the low-carbon technologies, etc.

National energy statistics make up a good source of data for the latter type of indicators, as they in many countries include data on the use of different types of energy production technologies in the domestic energy systems. Figure 26 shows the development in the use of different types of renewable energy technologies in the energy production in the Danish energy systems over the latest decades. It can be seen that biomass based energy constitutes the majority of renewable energy produced in Denmark. Also wind energy constitutes a considerable share. Of the rest of the covered technologies, heat pumps and biogas are the most used technologies.

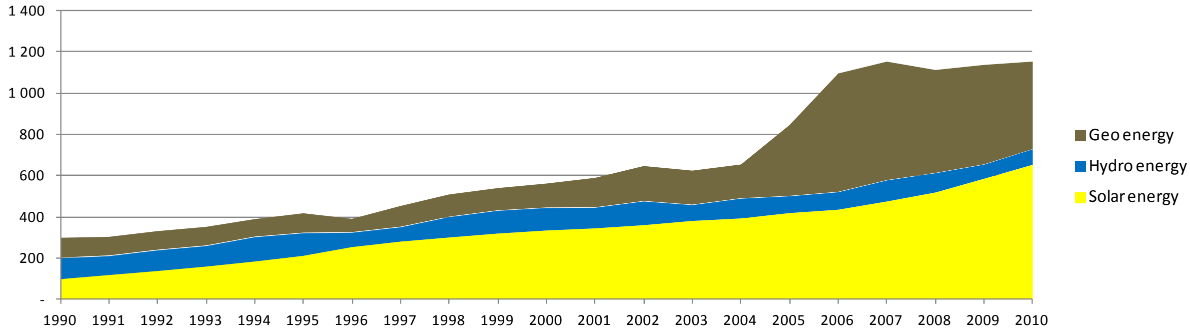
*Figure 26: Renewable energy production in Denmark, TJ. 1990-2010.*




Source: ENS (2011).

Figure 27 shows an enlarged picture of the smallest renewable energy production technologies (included in 'Other' in the previous figure). Though small in the general picture, it is interesting to notice the details. The use of solar energy has increased steadily over the period, while geothermal energy has varied more, though a general increase has taken place. Hydro energy is the only type of the renewable energy technologies covered which use has not grown in generalover the 20 years period.

*Figure 27: Renewable energy production in Denmark – the small ones, TJ. 1990-2010.*



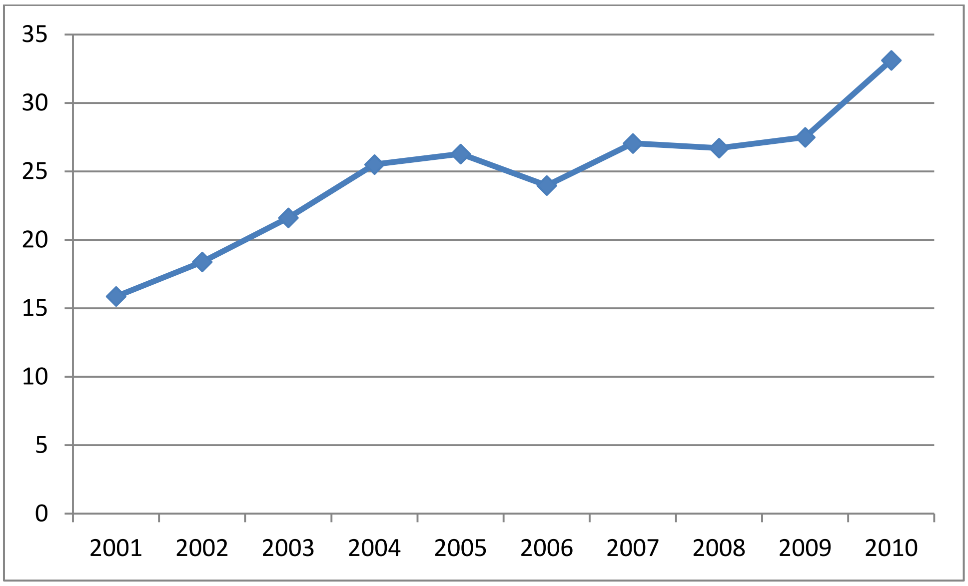

Source: ENS (2011).

Though the production of renewable energy has increased significantly since 1990, as the figures above show, the relative share of renewable energy in the primary energy production has only increased from around 11% to 14% over the period, due to increase in also other types of energy production, not least natural gas (ENS, 2011). A significant amount of the produced gas and oil is exported.

If one considers the greening of the national energy systems as an output indicator of the energy innovation systems, it can also be relevant to look at the share of renewable energy in the total consumption of energy. This has increased significantly from 6-7% in 1990 to around 20% in 2010 (ENS, 2011).

Figure 28 shows the development in the percentage share of electricity generated from renewable sources in Denmark. As appears there has also here been a significant development: this share more than doubled in the last decade, and the renewable sources in 2010 account for more than 30% of the electricity (ENS, 2011).

*Figure 28: Electricity generated from renewable sources in Denmark, percentage of total, 2001-2010.*



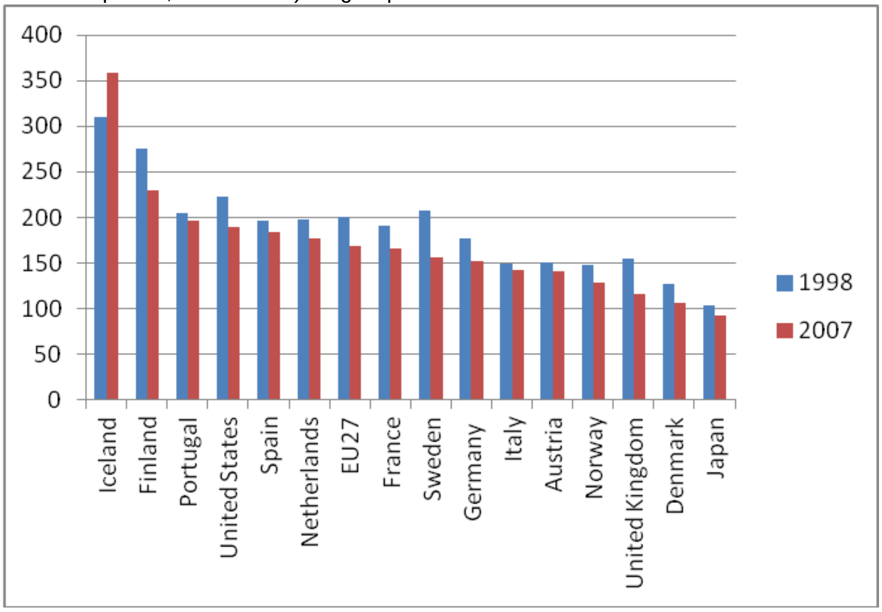

Source: Eurostat

### 3.3.2 Application of energy efficiency technology

Domestic application of energy efficiency technologies is more difficult to measure than the application of renewable energy production technologies etc. addressed above. One possibility is to identify specific product types and measure the extent of their application either in economical terms (trade of products) or in technical terms (amounts of units installed or energy consumption or efficiency figures). As energy efficiency issues appear in a lot of different product and application areas and as energy efficiency is often a relative issue related to the already existing practices in the specific application areas, it is highly difficult to establish a general and homogeneous way of measuring the application of energy efficiency products in total. Hence, the product focused approach can be said to be a bottom up strategy where one can succeed in measuring the application in a limited number of areas on micro level or branch level, but where it is difficult to get the full, macro level picture.

Another, opposite, possibility is a macro level measuring strategy, where one uses macro level statistics on energy consumption and measures the developments in energy intensity, i.e., the developments in energy consumption in relation to developments in activities. The activities can on macro level be measured in GDP. Figure 29 shows the energy intensity of different countries, reflecting the energy consumption of the economy and its overall energy efficiency. It is calculated as the ratio of gross inland energy consumption divided by the gross domestic product (in constant prices, base year 1995).

Figure 29: Energy intensity of the economy - Gross domestic consumption of energy divided by GDP (at constant prices, 1995=100) - kgoe per 1000 €. 1998 and 2007.

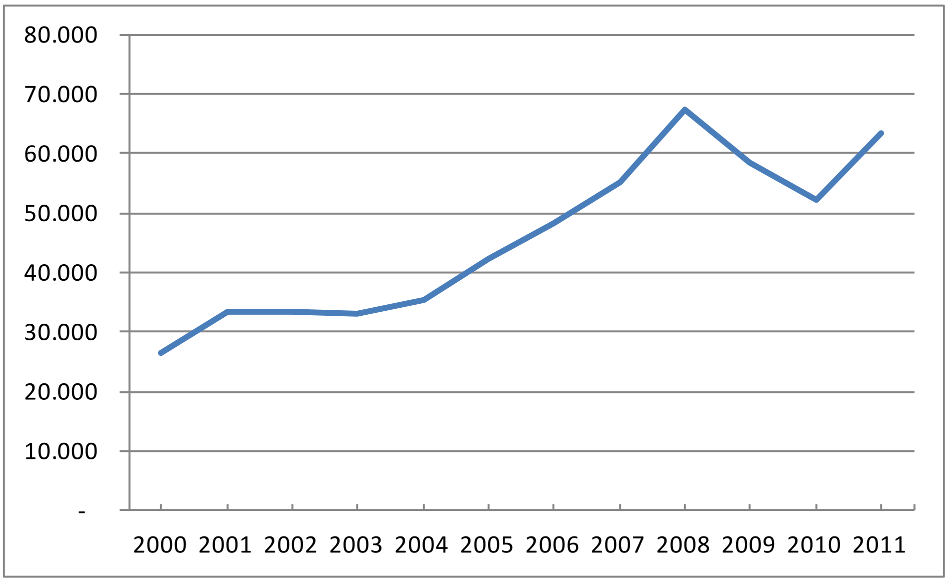



Source: Eurostat
Note: Latest available year for Iceland is 2006

### 3.3.3 Energy technology exports

Energy technology export is one of the important outputs of energy technology development. Danish authorities have in collaboration with Statistics Denmark and Danish Energy Industries Federation established an energy industry statistics with a.o.t. figures of energy technology exports. The development in the exports is shown in the following figure. A significant increase has appeared over the latest decade.

*Figure 30: Exports of energy technology and equipment from Denmark. Mill. DKK. 2000-2011.*




Source: ENS et al. (2011, 2012).

The export figures build on Eurostat's (Comext database) nomenclature for commodities (Dræbye, 2010). Export figures for individual areas of energy technologies are not published. Therefore it can be relevant to make additional analyses building on the general databases of industrial trade and commodities.

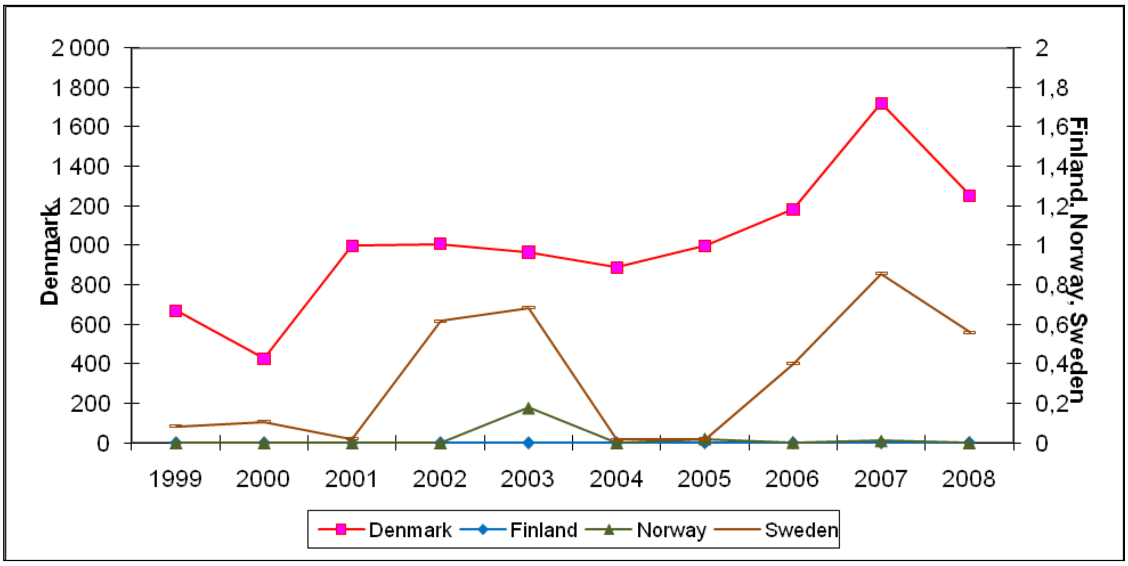
The UN database Comtrade can also be used for measuring energy technology exports. However, the list of commodities included in this database does not allow coverage of all energy technologies covered by this scoreboard. There are commodities which address *wind power* (HS 850231) and *hydropower* (HS 841011-13, 841090). For this scoreboard we use just wind power technologies. As has been pointed out by Johnstone and Hascic (2009b), *solar photovoltaic* technology may be covered by HS 8541.40, but the commodity group includes not only photovoltaic devices but also light-emitting diodes and semiconductor devices and is therefore far too broad.

*Table 19: Wind energy relevant Harmonised Commodity Codes*

| | |
|---|---|
| Chapter 85: | Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles |
| Heading 8502: | Electric generating sets and rotary converters |
| HS 850231 | Wind-powered generating sets |

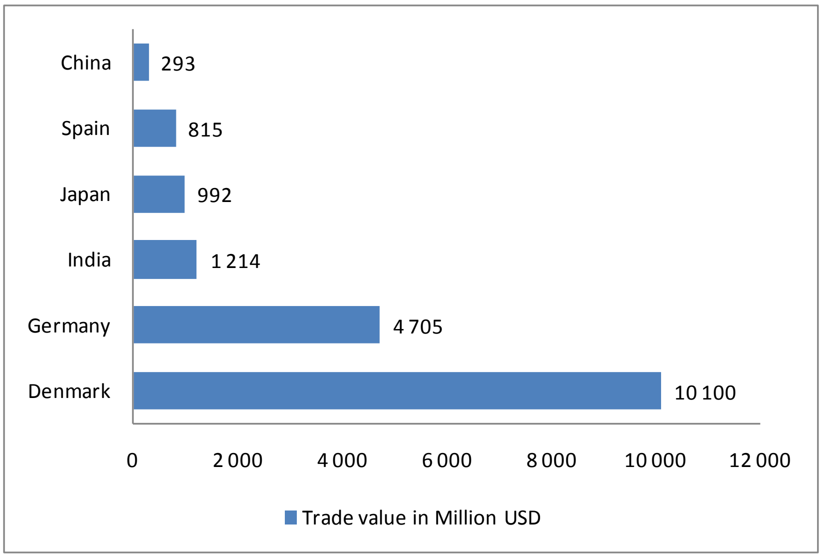
Most of the Nordic export of wind technology comes from Denmark, which is shown in Figure 40. When observing the figure it should be kept in mind that two different axes with different scales have been used; the left one for Denmark and the right one for the other Nordic countries. Export of Danish wind technology has been compared with the rest of the world. Figure 41 illustrates the leading position of Danish wind technology export in a global context.

*Figure 31: Wind technology export from the Nordic countries. 1999-2008. Mill. USD.*




Source: UN Comtrade Database.

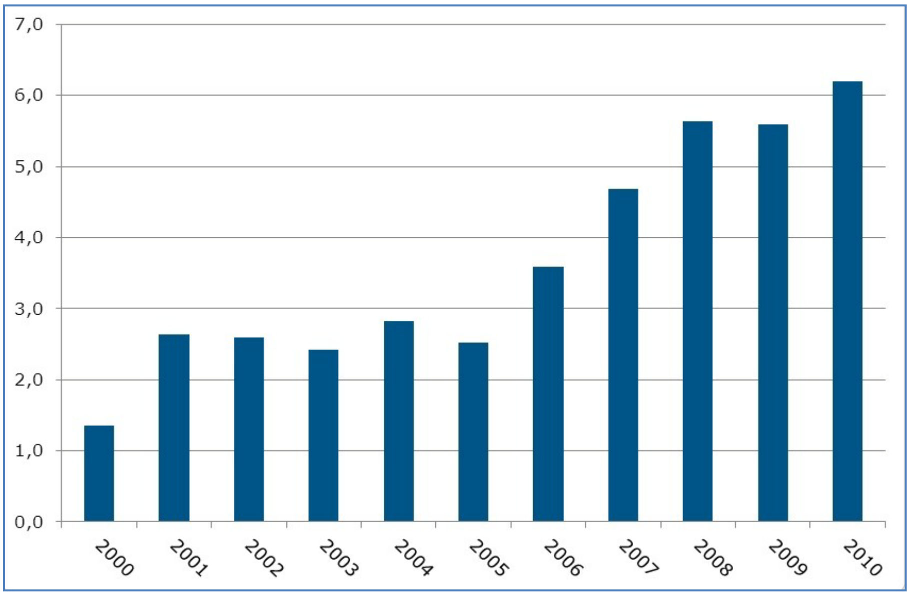
*Figure 32: Trade value of exported wind technology. 1999-2008. Mill. USD.*




Source: UN Comtrade Database.

It is interesting to notice that the exports figures building on the UN Comtrade database are significantly smaller than the figures from the industry statistics published by the Danish Wind Industry Association (2011), see below.

*Figure 33: Wind industry exports from Denmark. Billion Euros. 2000-2010.*



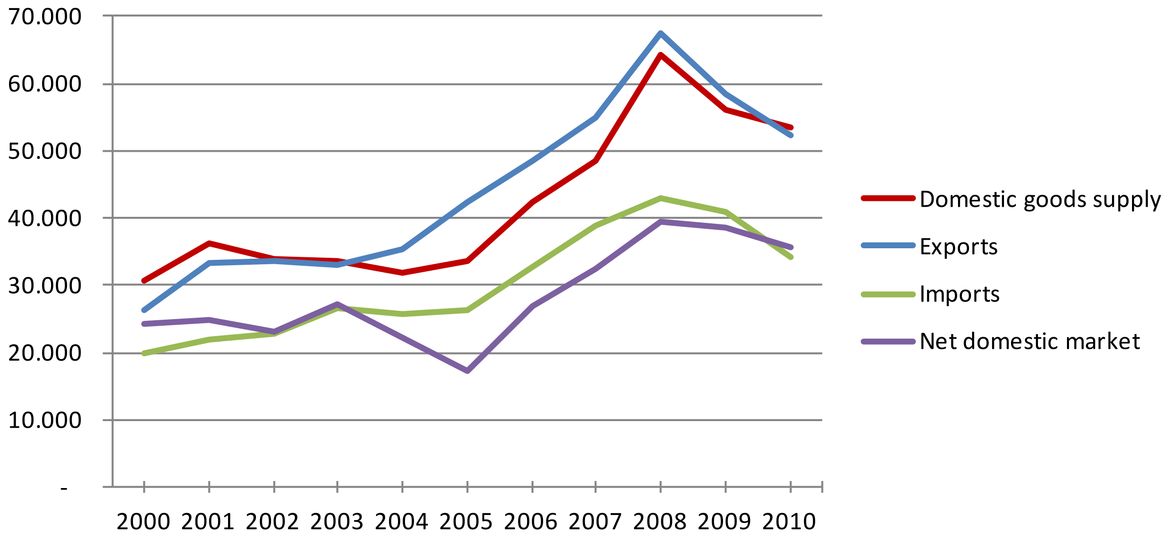

Source: Danish Wind Industry Association (2011).

Another indicator type that can offer insight in the international competitiveness and technology supply from Danish industry is the share of the world market by the Danish products in individual areas of energy technology. Apart from in economic terms, this can also be measured in energy terms, e.g., share of the globally installed energy effect in a year stemming from Danish technology manufacturers, or share of the total number of new-established energy production plants. Data availability is often a problem here, but in some cases trade literature and reports from international institutions and industry observers make accounts of market shares by different countries or by manufacturers that can be referred to specific countries (see Borup et al., 2008 for examples).

### 3.3.4 Domestic market

The Energy industry statistics also measures the size of the domestic market and trade of energy technology and equipment in economic terms. As appears from Figure 34, the size of the net domestic market is in the order of 35-40 billion DKK. Though it has been smaller than the exports since the beginning of the century, it is still considerable.

*Figure 34: Goods supply and net domestic market for energy technology and equipment from Denmark. Mill. DKK. Net domestic market = Domestic goods supply + imports – exports.*

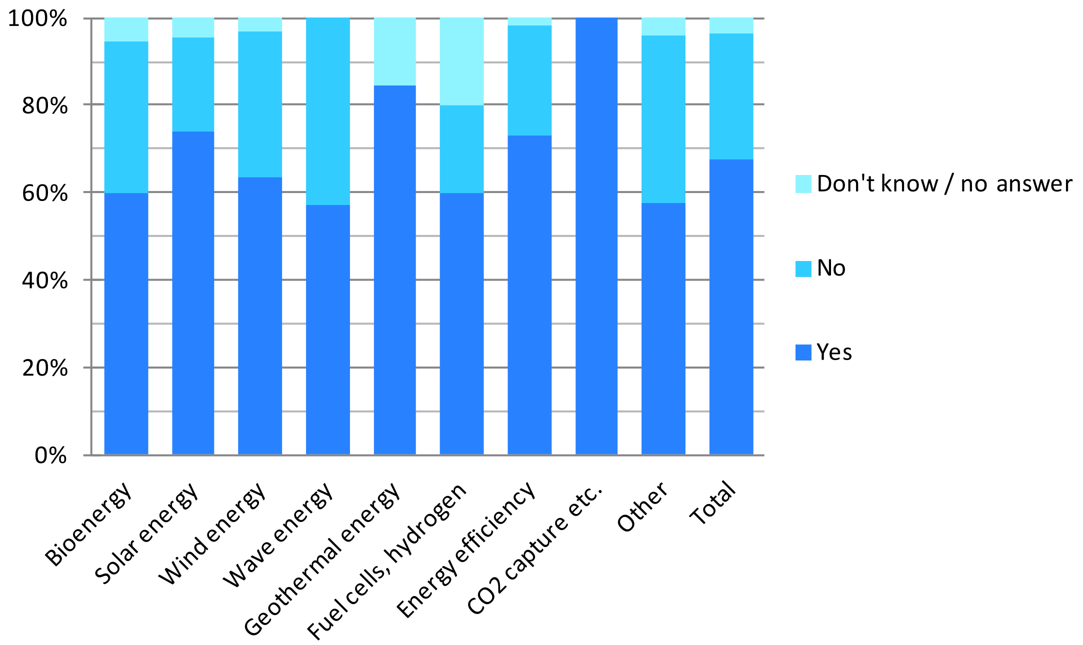



Source: ENS et al. (2011).

### 3.3.5 Market introduction of new technological products and services

The frequency of market introduction of new technological products and services is measured in the EIS survey (Borup et al., 2012) and is another business-related output indicator of energy innovation systems. The measuring is made with a method that makes the results directly comparable with the general national and European innovation statistics by Statistics Denmark and Eurostat (these other statistics do not cover the energy area separately). As appear from the Total column in Figure 35, 2/3 of the companies in the Danish energy innovation system have introduced new energy technology products or services in the period 2009 to 2011.

*Figure 35: Introduction of new energy technology products or services by companies in the period 2009-2011. All companies, EIS Survey 2011, N=314.*



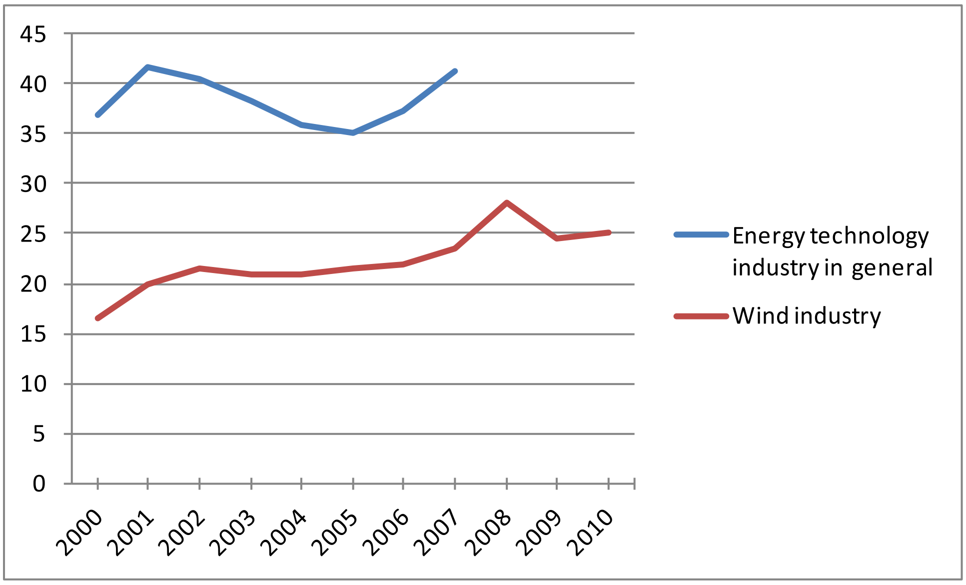

The figure varies between the technology areas, e.g. with a share of more than 70% in the area of energy efficiency technology and around 60% within bioenergy and wind energy. The data on geothermal energy and on $CO_2$ capture builds on a limited amount of cases.

### 3.3.6 Employment

Employment in the energy technology industry is another important output indicator of the energy innovation system. Figures from the Energy industry statistics (ENS et al., 2011) are available for the period 2000–2007, see Figure 36. These figures cover the energy technology industry in general and show an employment in the industry in the order of 35–40.000 persons, increasing in the period from 2005 to 2007 to around 41.000 after some years of decrease since 2001.

In addition, figures for the wind technology industry up till 2010 are available from the Danish Wind Industry Association. These show a generally increasing tendency in the employment from around 16.000 employees in the wind industry in the beginning of the millennium to 25.000 a decade later. Juxtaposed with the general employment data, it is clear that the wind area make up a considerable share of the total employment within the energy technology industry in Denmark. Around half of the employment is in the wind energy area, and the share has been increasing.

*Figure 36: Employment in the Danish energy technology industry in general and in the wind industry (in thousand employees).*




Sources: ENS et al. (2011) (general) and Danish Wind Industry Association (on wind industry).

These employment figures illuminate the total employment, independently of what the work activities more specifically consist in and whether they have to do with innovation and development activities or not. That is the reason why we here mention them among the output indicators from the energy innovation system. However, if one focus on only employees that directly work with innovation and development activities or have an innovation and R&D oriented education, the employment figures can also be considered as input indicator. There are examples of that measuring of such indicators is possible from some general trade and industry statistics, however to our knowledge this has not been done for the energy area specifically.

# 4 Conclusions

Probably, nobody would deny that the indicators and graphs presented above give a lot of interesting information and insight on many points. The question is however: How well do the available indicators cover the energy innovation system?

The general picture is that there is some information available both concerning the innovative performance and resulting output of the energy innovation system (output indicators), the interplay and activities in the innovation system (throughput indicators) and the supporting platform and investments in it (input indicators).

Of the seven overall functions for establishment of new technologies, six are covered to some extent: knowledge development, knowledge exchange in networks, market formation, mobilization of resources, legitimacy, and entrepreneurial activities. The seventh function, guidance of the search, is not covered.

*Table 20: Coverage of indicators of the different functions in the innovation systems.*

| | | Indicators | I/T/O | Covered? |
|---|---|---|---|---|
| **Functions:** | | - | | |
| **Entrepreneurial activities and experimentation** | | - Experimental application projects<br>- New product introductions<br>- New businesses | T<br>O<br>O-T | Limited (only R&D)<br>Yes<br>No (some e.g. in EIS survey) |
| **Knowledge development (learning)** | | - Scientific publications<br>- Technology application (learning-by-using)<br>- R&D funding<br>- Patents | T-I<br>O-T<br>I<br>T | Yes<br>Yes<br>Yes, public (not private)<br>Yes |
| **Knowledge exchange in networks** | | - Collaboration patterns<br>- Demonstration projects<br>- Network participation<br>- Conferences and debate meetings | T<br>T<br>T<br>T | Yes<br>No. Public demo possible<br>Limited<br>Limited |
| **Market formation** | | - Market application<br>- Public market support<br>- Exports<br>- Standards and certifications | O<br>I<br>O<br>T | Yes (Energy eff. limited)<br>No. Some is available (?)<br>Yes, not all technologies<br>No |
| **Mobilization of resources** | | - R&D funding<br>- Investments<br>- Personnel<br>- R&D / others | I<br>I<br>I / O | Yes, public (not private)<br>Only public R&D programmes<br>Partly |
| **Guidance of the search – shared visions** | | - Policy action plans<br>- Shared strategies and roadmaps | I<br>I-T | No<br>No |
| **Legitimacy** | | - Public opinions on energy technologies and systems<br>- Regulatory acceptance and integration | I<br>T-I | Yes<br>No |

Note: I,T,O indicate input, throughput and output indicators.

In this sense, there are few really big blind, uncovered fields. When this is said, it is also clear that the coverage could on many points be much better and more complete. On most of the functions, the coverage is still scattered and incomplete.

Moreover, the coverage of individual areas of energy technologies and products is often limited. The lack of adequate product classes in the existing industry and trade statistics is one of the reasons for this.

Other observations are:

- The area of energy efficiency technology is a complex area that is often difficult to measure and that needs special attention if it shall be covered better in the set of indicators.

- The definition and delimitation of the individual energy technology areas is often difficult. The juxtaposition of different definitions in this report offers a rare chance of comparing them. There are moreover differences between the definitions and key words used for an individual technology area in different analyses. To some extent this is natural, however it is worth considering if something can be gained by an increased harmonization of the set of keywords, etc., used.

- The general statistics institutions on national, European, and international levels do only to a very limited extent offer insight in energy innovation systems. It would be useful if the efforts on updating classification systems for goods, industrial branches, etc., are reinforced in order to better reflect energy innovation and change towards sustainable energy systems.

# Annex

## List of acronyms

| | |
|---|---|
| € | Euro |
| BERD | Business Expenditures on R&D |
| CCS | Carbon dioxide Capture and Storage |
| CIS | Community Innovation Survey, EU |
| DENP | Danish Energy R&D projects |
| ECLA | European Classification |
| EIS | 1. European Innovation Scoreboard |
| | 2. Strategic research alliance on Energy Innovation System and their dynamics |
| ENS | Energistyrelsen |
| EPO | European Patent Office |
| ERMINE | Electricity Research Road Map in Europe |
| ERTD | Energy Research, Technology and Development |
| EST | Environment Sound Technologies |
| EU or EU-27 | European Union |
| EW | ERAWATCH |
| GBAORD | Government Budget Appropriations or Outlays on R&D |
| GDP | Gross Domestic Product |
| HRST | Human resources in Science and Technology |
| HS | Harmonised Commodity Description and Coding System |
| ICTSD | International Centre on Trade and Sustainable Development |
| IEA | International Energy Agency |
| IEADCC | IEA Climate Change Database |
| IPC | International Patent Classification |
| IPTS | Institute for Prospective Technological Studies (of the JRC) |
| ISI WoS | ISI Web of Science |
| ISIC | International Standard Industrial Classification |
| JRC | Joint Research Centre (of the European Commission) |
| MEI | Measuring eco innovations |
| MS | Member State of the European Union |
| NACE | Statistical Classification of Economic Activities |
| OECD | Organisation for Economic Co-operation and Development |
| PPP | Purchasing Power Parities |
| PV | Photovoltaic |
| R&D | Research and Development |
| RD&D | Research, Development and Demonstration |
| RCTA | Revealed Comparative Technology Advantage |
| RON (95) | Research Octane Number ("EuroSuper" or "EuroPremium") |
| RTD | Research Technology Development |
| SET-Plan | (European) Strategic Energy Technology Plan |
| S&T | Science and Technology |
| UN | United Nations |
| UNEP | United Nations Environment Programme |
| USD | US Dollar |
| WEC | World Energy Council |
| 2G | Second generation |

## Unit abbreviations

| | |
|---|---|
| GJ | Gigajoule |
| GW | Gigawatt |
| GWh | Gigawatt hour |
| kcal | kilocalorie |
| KJ | kilo joule |
| kgoe | kilogram of oil equivalent |
| kW | kilowatt |
| kWh | Kilowatt hour |
| Mt | Million tonnes |
| Mtoe | Million tonnes of oil equivalent |
| MW | Megawatt |
| MWh | Megawatt hour |
| MWe | Megawatt electric |
| MWth | Megawatt thermal |
| PPP | Purchasing power parity |
| Toe | Tone of oil equivalent= 107 kcal |
| TWh | Terawatt hour |

## Keywords for bibliometric mapping

### $2^{nd}$ generation biofuels

Cellulosic bioethanol
Biomass-to-liquid*
Fischer-Tropsch diesel
Synthetic biodiesel
Synthetic diesel
Bio-methanol
Synthetic natural gas
Lignocellulosic biomass*
Lignocellulosic material*
Gasification synthesis
Anaerobic digestion
Hydrolysis fermentation
Advanced biofuel*
Advanced bioenergy
2nd generation biofuel*
Advanced bioethanol
Bio* pyrolysis

### Fuel cells

Fuel cell*
SOFC
AFC
PEFC
PEMFC
Molten carbonate
Nafion membrane*
ZrO2*
YSZ electrolyte

### Photovoltaic energy

Solar photovoltaic
Solar AND silicon*
Solar cell*
Silicon* AND wafer
Photoelectrochemical Cell*
Thin film*
Anti-reflection coating
Screen printing

### Wind energy

Wind energy
Wind power
Wind turbin*
Wind mill*
Offshore wind*
Onshore wind*
Airborne turbine*
Near-shore turbine*
Wind resource assessment
Wind farm*
Upwind rotor*
Horizontal-axis rotor*
Pitch regulation
Stall regulation
Variable-speed drive
Doubly-fed induction generator
Permanent magnet generator - full converter
Joined blades
Blade winglet*
Slew-ring-type bearings

## Main EST categories for patent mapping

This table is taken from the EST inventory on energy generation used by the joint EPO/UNEP/ICTSD study (Klitkou et al., 2010, p. 82ff.).

| | | | number of documents (1) | IPC source |
|---|---|---|---|---|
| ENE RGY GENERATION: | | | | |
| | | | | |
| geothermal | | | 5342 | F24J3, F03G4 and parts of F03G7/04 |
| | Earth coil heat exchangers | | 597 | part of F24J3/08 |
| | Hot Dry Rock systems (drilling) | | 357 | part of F24J3/08 |
| | geothermal heat pump (for buildings) | | 140 | part of F24J3/06 |
| | Hardware (pipes) | | 1202 | part of F24J3/08 |
| | | | | |
| | | | | |
| hydro | | | 44124 | mainly F03B |
| | conventional | | 13970 | F03B1, F03B3, F03B7 |
| | OTEC (ocean thermal energy conversion) | | 591 | F03G7/05 |
| | OWC (oscillating water column) | | 530 | part of F03B13 |
| | salinity gradient | | 1020 | part of F03G7/04 |
| | stream (river and tidal) | | 4479 | parts of F03B13/26 and F03B17/06 |
| | wave (pelamis etc.) | | 6960 | F03B13/14 |
| | | | | |
| Solar energy (3): | | | | |
| | solar thermal | | 62487 | mainly F24J2 |
| | | dish | 1330 | F24J2/12 |
| | | Fresnel lenses | 942 | part of F24J2/08 |
| | | trough concentrators | 2043 | F24J2/14 |
| | | tower concentrators | 1729 | F24J2/07 |
| | | heat exchange systems | 26299 | other parts of F24J2 |
| | | mountings and tracking | 7555 | F24J2/38, 2/52, 2/54 |
| | | mechanical power | 3418 | parts of F03G6 |
| | | | | |
| | PV (photovoltaic) | | 83330 | Mainly parts of H01L31 (most H01L31/04) |
| | | amorphous Si | 2312 | parts of H01L31/075, 31/0376 and 31/0368 |
| | | CuInSe2 materials | 1568 | parts of H01L31/032, 31/0336 |
| | | pv with concentrators | 6220 | H01L31/052, 31/042, 31/058 |
| | | DSSC (dye sensitized solar cells) | 4170 | parts of H01G9/20 |
| | | group II-VI materials | 1529 | parts of H01L31/072, 31/18 |
| | | group III-V materials | 2556 | parts of H01L31/068, 31/072, 31/18E, 31/0304 |
| | | microcrystalline Si | 193 | parts of H01L31/18 |
| | | polycrystalline Si | 504 | parts of H01L31/18 |
| | | pv roof systems | 4800 | parts of h01l31/048 and E04D13/18 |

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| | | | | |
| | thermal-pv hybrids | | 1590 | H01L31/058 |
| | | | | |
| wind energy (4): | | | 37995 | Mainly F03D |
| | blades and rotors | | 9859 | F03D1/06, 3/06 |
| | components and gearbox | | 11251 | F03D11/00, 11/02 |
| | control of turbines etc. | | 9508 | F03D7 |
| | generator and configuration | | 5243 | F03D9/00, parts of H02K7/18 |
| | nacelles | | 605 | parts of F03D |
| | offshore towers | | 830 | parts of : F03D1, 11/04, E04H12/14 and B63B35 |
| | onshore towers | | 6030 | parts of : F03D1, 11/04, E04H12/14 |
| | | | | |
| Biofuels (5) | | | | |
| | CHP turbines for bio-feed | | 1307 | parts of F02C6/18 |
| | Gas turbines for bio-feed | | 626 | parts of F02C3/28 |
| | bio-diesel | | 2324 | parts of C10L, C10G, C11B, C11B, C07C67 |
| | bio-pyrolysis | | 4550 | C10C5/00, parts of C10B53/02 |
| | torrefaction of biomass | | 120 | parts of C10L9, C10L5/40, C10B53/02 |
| | bio-ethanol: cellulosic | | 1672 | C12P7/10 |
| | bio-ethanol: grain | | 5894 | C12P7/06 |
| | bio-alcohols produced by other means than fermentation | | 208 | parts of C07C29, C07C31 |
| | | | | |
| | | | | |
| AUXILIARY TECHNOLOGIES: | | | | |
| | | | | |
| Carbon Capture and Storage (1): | | | | |
| | capture (1.1): | | | |
| | | CO2 absorption | 2699 | parts of B01D53/14 |
| | | CO2 adsorption | 2387 | parts of B01D53 |
| | | CO2 biological separation | 94 | parts of B01D53 |
| | | CO2 chemical separation | 2008 | parts of B01D53/62 |
| | | CO2 removal via membrane/ diffusion | 998 | parts of B01D53/22 |
| | | CO2 removal via rectification and condensation | 1328 | parts of F25J3/02, 23/06 |
| | | | | |
| | CO2 storage (subterranean or sub-marine) | | 730 | parts of F17C1/00, E21B41/00 |
| | | | | |
| Energy Storage (2) | | | | |
| | Fuel cells (2.1) | bio fuel cells | 887 | parts of H01M |
| | | DMCF+DAFC | 10251 | " |
| | | MCFC | 3545 | " |

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|---|---|---|---|---|
| | | PEMFC | 21508 | " |
| | | recycling of fuel cells | 2571 | " |
| | | SOFC | 16346 | " |
| | | | | |
| | Advanced batteries (2.2) | | | |
| | | charge management | 104202 | parts of H01M |
| | | Flow | 2158 | " |
| | | lithium-ion | 57392 | " |
| | | NiMH | 4131 | " |
| | | recycling of batteries | 2528 | " |
| | | ultra-capacitors | 6583 | " |
| | | | | |
| | | | | |
| IGCC (3) | IGCC | | 2528 | parts of C10L3, F02C2/28, 6/18, F01K23/06 |
| | IGCC with CCS | | 22 | parts of C10L3, F02C2/28, 6/18, F01K23/06 |
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(1) The number of families is roughly one third of the number of documents indicated.

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